BACHELORTHESIS–ME141502

THE EFFECT OF MATERIAL SELECTION BASED ON THERMO MECHANICAL STRESS ANALYSIS OF PISTON SYSTEM ON SEMI FREE PISTON TWO STROKE DIESEL ENGINE DUAL OPPOSITE

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Surabaya 2016

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PENGARUH PEMILIHAN BAHAN BERDASARKAN ANALISA TEGANGAN THERMO MEKANIK SISTEM PISTON PADA SEMI FREE PISTON TIPE DUA LANGKAH BERPISTON GANDA BERLAWANAN ARAH

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JURUSAN TEKNIK SISTEM PERKAPALAN
Fakultas Teknologi Kelautan
Institut Teknologi Sepuluh Nopember
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APPROVAL FORM

The Effect of Material Selection Based On Thermo Mechanical Stress Analysis of Piston System On Semi Free Piston Two Stroke Diesel Engine Dual Opposite

Bachelor Thesis

Submitted to Comply One of the Requrements to Obtain
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On
Laboratory of Marine Power Plant (MPP)
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ABSTRACK

Free piston engines have disadvantage due to the angular moment. The angular moment cause misfire in the engine. Semi Free Piston is the innovation engine design that could eliminates the angular moment by applying keyways on connecting rod. Analysis in this research includes mechanical stress, thermal stress and thermo mechanical stress of piston. Analyzed also conducted to mechanical stress distribution received on connecting rod. Maximum thermo mechanical stress of piston occurred was used material Alumuium A 4032 value 259.27 MPa. Maximum mechanical stress of connecting rod was used material C-70 and piston material Alumunium A 4032 value 92.35 MPa. Results thermo mechanical stress analysis of piston material AL GHS 1300 have a greatest consideration for selected material piston. Based on mechanical stress distribution analysis connecting rod material C-70 have greatest consideration for selected material connecting rod.

Keywords: Connecting Rod, Piston, Finite Element Method, Semi Free Piston Linier Engine, Thermo mechanical stress.

PENGARUH PEMILIHAN BAHAN BERDASARKAN ANALISA TEGANGAN THERMO MEKANIK SISTEM PISTON PADA SEMI FREE PISTON DIESEL ENGINE TIPE DUA LANGKAH BERPISTON GANDA BERLAWANAN ARAH

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ABSTRAK

Free piston engine memiliki kekurangan akibat terjadinya moment angular. Terjadinya moment angular menyebabkan misfire pada mesin. Semi free piston adalah inovasi desain mesin yang dapat mengeliminasi moment angular dengan mengaplikasikan *keyways* pada *connecting rod*. Analisa dalam penelitian ini meliputi tegangan mekanik, thermal, dan thermo mekanik piston. Serta dilakukan analisa tegangan distribusi mekanik yang diterima oleh *connecting rod*. Hasil dari tegangan termo mekanik maksimal piston terjadi pada material Alumunium A 4032 senilai 259.27 MPa. Tegangan mekanik connecting rod maksimal terjadi pada material C-70 dengan menggunakan material piston Alumunium A 4032 senilai 92.35 MPa. Hasil analisa tegangan termo mekanik piston material AL GHS 1300 memiliki pertimbangan yang terbaik untuk digunakan pada pemilihan material piston. Berdasarkan tegangan mekanik connecting rod material C-70 memiliki pertimbangan terbaik untuk digunakan pada pemilihan material *connecting rod*.

Kata kunci: *Connecting Rod, Finite Element Method, Piston, Semi Free Piston Linear Engine*; Tegangan Termo Mekanik.

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CHAPTER I
INTRODUCTION

1.1 Background

In the use of conventional diesel engines is now commonly used as a means of driving means of transportation as well as industry support tools. The use of this type of engine is based from other types of engine that can produce better efficiency overall. However from some aspects, such a conventional diesel engine still has a some hortage in terms of friction and power generated. That is because one third of the losses due to friction caused from against parts such as the crankshaft and bearings. (Nandkumar, 1998).

In the modern era has been a lot of innovation that has been studied for generating efficiency of engines has led to various types of engines, however the various innovation still has deficiency regarding friction. Free piston engine or linear engine is one of the studies that are considered to cover some of the deficiency of other types of conventional machines. Research on free piston engine search has been carried out. Free piston engine efficiency can improve the engine and also produces lower friction than conventional machines.

At this time free piston engine is an innovation that can reduce friction by utilizing the linear movement without having connection to the crankshaft. By using free piston engine will obtain a machine that has a compact system. Compact system components that exist on a linear engine will reduce losses resulting from operating the machine. In addition to the linear engine compact system will influence the cost of making and will facilitate machine maintenance.

From research motion study compare conventional two stroke engine and free piston two stroke engine. The friction force has a strong influence on the piston acceleration, especially in the TDC and BDC zones due to the extremely fluctuating trends. Moreover, the piston has a rotary motion which would influence the scavenging process. This is alarming for a two stroke engine with a conventional scavenging piston control system. The pure free piston could affect the combustion process of a linear engine Fathallah et al (2014).

Linear engine have a various types based on piston construction such as free piston have one piston or called single piston. Also free piston with two piston or called dual piston. Could said free piston because connection between cylinder liner and piston have independently motion. However in this thesis research used design semi free piston two stroke diesel engine dual cylinder opposite system. (Fathallah and Barus, 2015).

After stage of design semi free piston two stroke diesel engine dual opposite system engine have been completed and know performance of the engine necesarry to know material selection in piston system parts and how the thermal stress analysis on piston system. For analys thermal stress, in the past research will using experimental method. Analysis thermal stress analysis can using finite element method to prediction thermal stress and mechanical stress in the piston system. With using finite element method to prediction thermo mechanical stress will obtained fast analyzed and reduce cost of research.

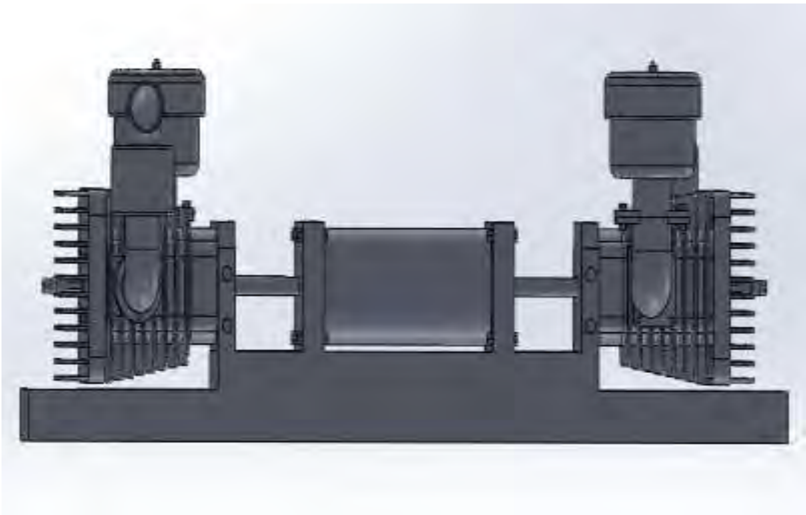

Figure 1.1 Design Semi Free Piston Linear Engine
(Source:Fathallah and Barus, 2015)

In this research will using finite element method which are expected prediction a real value thermo mechanical stress according to material selection piston system from engine model design semi free piston two stroke diesel engine dual opposite system which has been designed (Fathallah and Barus,2015). Writer be expected with using finite element method software thermo mechanical stress in piston system from the engine which will be analyzed. Writer in this thesis will obtain appropriate analysis mechanical stress, thermal stress, and thermo mechanical stress.

1.2 Statement of Problems

Based on background in this research thesis statement of problems in this thesis are:

1. How the effect of selection material piston based on mechanical stress design piston semi free two stroke diesel engine dual opposite?
2. How the effect of selection material piston based on thermal stress design piston semi free two stroke diesel engine dual opposite?
3. How the effect of selection material piston based on thermo mechanical stress design piston semi free two stroke diesel engine dual opposite?
4. How the effect of selection material connecting rod based on mechanical stress design connecting rod semi free two stroke diesel engine dual opposite

1.3 Research Limitations

Research limitation in this research are:

1. The analyzes were conducted at steady state conditions.
2. Piston system components which analyzed only piston and connecting rod.
3. Economic terms were not analyzed.
4. Factor of friction piston are ignored.

1.4 Research Objectives

This research aims to:

1. Determine the effect of material selection based on mechanical stress caused by pressure cylinder combustion that occurs in piston.
2. Determine the effect of material selection based on thermal stress caused by temperature distribution that occurs in piston.
3. Determine the effect of material selection based on thermo mechanical stress caused by pressure cylinder combustion and temperature distribution that occurs in piston.
4. Determine the effect of material selection based on stress caused by pressure cylinder combustion that occurs in connecting rod.

1.5 Research Benefits

In this research benefit determine how the distribution of thermal and mechanical stress so could be used as reference material selection of the piston and connecting rod design semi free piston two stroke diesel engine dual opposite.

CHAPTER II
STUDY LITERATURE

2.1 Literature Review

Research on linear free piston engine ever made by making a simulation of the performance of free-piston linear engine compared with a conventional engine. Free-piston linear engine has advantages compared with conventional engines that frictional losses are reduced because the system is simple. If the problem of motion of the piston is not investigated, but it should be resolved so that the concept of free-piston linear engine becomes feasible. (Mikalsen and Roskilly, 2009).

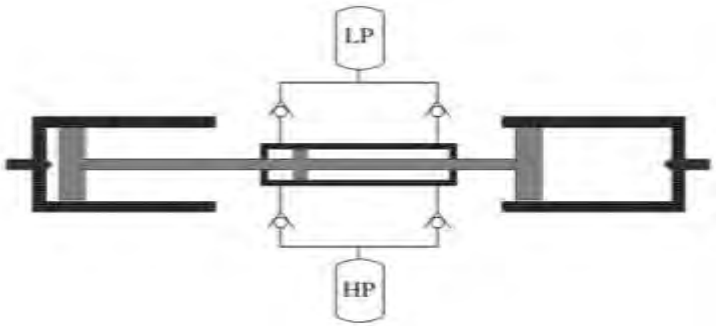

Figure 2.1 Dual Piston Free-Piston Engine
(Source: Mikalsen and Roskilly, 2009)

In the research of free-piston linear engine has advantages over the conventional engine in terms of fuel efficiency and low temperature makes it possible to reduce emissions. There are many to be studied to develop a linear engine that can be an alternative machine. More important for future research is about the problem of engine control and combustion linear free piston engine. (Mikalsen and Roskilly, 2009).

Free Piston Engine is a type of machine that does not use a crank shaft or so-called 'crankless' internal combustion engine. By not using the crank shaft linear free piston engine can minimize the friction that occurs when the machine is operating. Currently under construction application linear free piston engine is widely used as an propulsion for generating electrical energy in hybrid systems. Free piston have several type such as single piston, dual piston, and opposite system. (Mikalsen and Roskilly, 2009).

But free piston have disadvantage from moment angular, caused scavenging process not perfect and impact to the combustion process. In previous research motion study single cylinder linier engine, the rotary movement in piston linier engine was strongly correlated with angular momentum. Rotary movement in piston happen when friction between cylinder liner and piston ring can not be ignored (Fathallah et al ,2014).

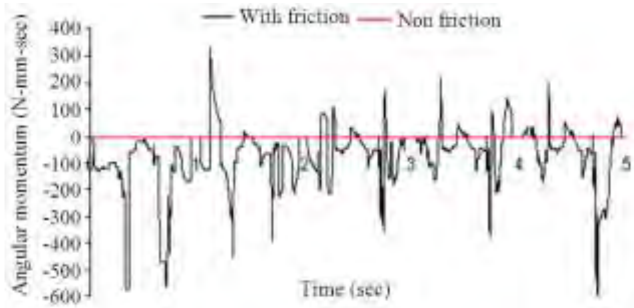

Figure 2. 2 Angular Momentum Single Cylinder in Z direction
(Source: Fathallah et al, 2014)

Innovation model of free-piston linear design of dual-piston engine has been carried out using keyways to eliminate angular moment happened in linerar engine. Research on the innovation of the design model is called the design model semi-free piston linear engine piston opposite dual system. The concept of design are in the design model piston system applied keyways, the concept design adopted from design of a propeller shaft with propeller that used a type of keyway. (*Fathallah and Barus, 2015).*

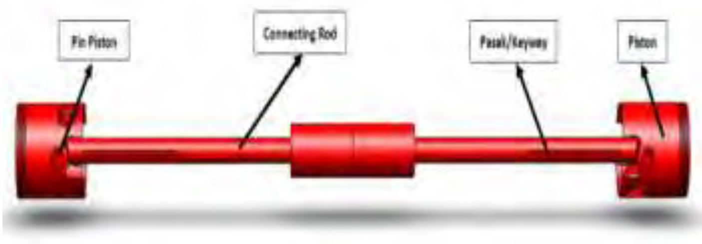

Figure 2. 3 Semi Free Piston Design
(Source :Fathallah and Barus, 2015)

It is important to calculate the piston temperature distribution in order to control the thermal stresses and deformations within acceptable levels. As much as 60% of the total engine mechanical power lost is generated by piston ring assembly. The piston skirt surface slides on the cylinder bore. A lubricant film fills the clearance between the surfaces. The small values of the clearance increase the frictional losses and the high values increase the secondary motion of the piston. Most of the Internal Combustion (IC) engine pistons are made of an aluminium alloy which has a thermal expansion coefficient, 80% higher than the cylinder bore material made of cast iron. *(Kumar et al. 2013).*

In engine, transfer of heat takes place due to difference in temperature and from higher temperature to lower temperature. Thus, there is heat transfer to the gases during intakes stroke and the first part of the compression stroke, but the during combustion and expansion processes the heat transfer take place from the gases to the walls. So the piston crown, piston ring and the piston skirt should have enough stiffness which can endure the pressure and the friction between contacting surfaces. In addition, as an important part in engine, the working condition of piston is directly related to the reliability and durability of engine. (Raj and Kumar, 2014).

In the research the finite element analysis of the thermal stress distribution of piston head. It is important to determine the piston temperature distribution in order to control the thermal stresses and deformations within acceptable levels. The temperature distribution enables the designer to optimize the thermal aspects of the piston design at lower cost, before the first prototype is built. In the distribution thermal stress in piston head, there are several parts obtained the distribution stress in piston systems. Parts piston, pin and connecting rod will received the thermal. *(Lungu, et al. 2013).*

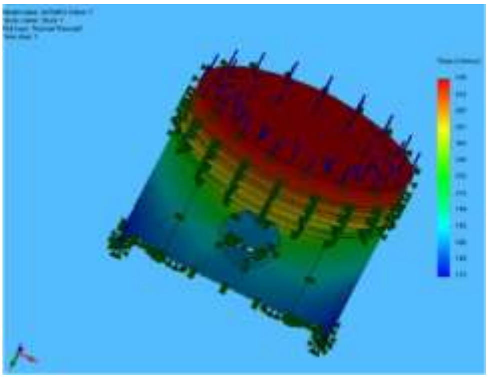

Figure 2. 4 Temperature Distribution Piston
(Source: Lunguet al. 2013)

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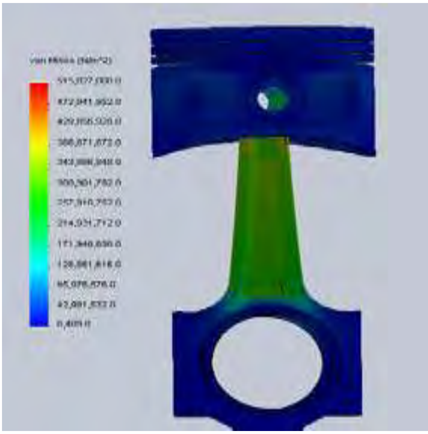

Figure 2. 5 Stress Distribution in Connecting rod
(Source:Srikanth et al. 2013)

It is important to calculate the piston temperature distribution in order to control the thermal stresses and deformations within acceptable levels. As much as 60% of the total engine mechanical power lost is generated by piston ring assembly. The piston skirt surface slides on the cylinder bore. A lubricant film fills the clearance between the surfaces. The small values of the clearance increase the frictional losses and the high values increase the secondary motion of the piston. Most of the Internal Combustion (IC) engine pistons are made of an aluminium alloy which has a thermal expansion coefficient, 80% higher than the cylinder bore material made of cast iron. *(Srikanth et al. 2013).*

Kumar et al (2014) defines piston in IC engine must posses the following characteristics. Strength to resist gas pressure, must have minimum weight. must be able to reciprocate with minimum noise. Piston in IC engine must have sufficient bearing area to prevent wear, must seal the gas from top and oil from the bottom. must disperse the heat generated during combustion. must have good resistance to distortion under heavy forces and heavy temperature. To analyzed thermal stress in piston characteristic of selection materials must to know are elastic modulus, ultimate tensile strength, yield strength, poisson's ratio, thermal conductivity, coeficient of thermal expansion and density. Deformation happend when limit of the material selection are more less than stress in piston area.

2.2 Stress

Stress arise from a wide variety of outside force, some of which is pressure, pull, and bending. In tensile loading occurs tension, the compressive stress loading occurs press, as well as the imposition of another. According to James and Stephen (1997) stress and strain is the most basic concepts in mechanics of materials. This concept can be illustrated in its most basic form by reviewing a prismatic rod experiencing axial force. Prismatic rod is a straight structural elements that have a constant cross-section throughout its length, while the axial force is a burden that has the same direction with the axis of the element, which causes the pull or pressure on the stem.

2.3 Thermal Stress

Thermal stress piston was caused by temperature distribution of the piston. There are several parameter of the material selection properties that can influenced into thermal stress:

- Density (kg/m3)
- Modulus Elasticity (N/m2)
- Poison Ratio
- Yield Strength Material (MPa)
- Thermal Conductivity (W/mc)

Stress can be caused by several things, one of which is because the heat is called the thermal stress. Ziman (1967) defines the thermal stress is the stress that occurs in a material as a result of temperature changes. It happened on the results of the temperature distribution in the different parts that are not uniform and the limitation on the possibility of expansion or contraction. As we know that, for some materials, the volume will change with changes in temperature. The increase or decrease in temperature will cause expansion and contraction. If the structure of the movement is restricted or detained when there is a change of temperature on the structure will arise tension (stress). Ziman (1967) declared thermal stress occurs on the result of temperature differences on the surface for rapid heating or cooling

$$\sigma = E\,\varepsilon$$
$$= E\,\alpha\,\Delta t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(1)$$

(Ziman, 1967)

Where:

σ = Thermal Stress (N/m2, Pa)

E = Modulus Elasticity (N/m2)

α = Coeficient Thermal Expansion (m/m°C)

Δt = Temperature Diferrence (°C)

2.4 Thermo Mechanical Stress

The piston is a component of diesel engine combustion processes affected, piston exposed to high pressure and temperature while burning. While the connecting rod is a machine component that serves to distribute the pressure of the piston . One of the factors that affect the magnitude of the stress that occurs on the piston is the material used. The material has chemical content and different properties . In the selection of a material to the stress factor here are the properties that affect the stress is tensile strength, yield strength, hardness, thermal conductivity, modulus of elasticity and etc.

On the piston there are two main types of loads that can cause stress that combustion pressure and temperature combustion at piston crown. In research analysis using ANSYS finite element analysis software. The study compared three kinds of stress received by the piston . Namely thermal stress caused by temperature piston when the combustion process, mechanical stress caused by the combustion pressure. As well as the combined stress or thermo mechanical stress caused by the combustion pressure and temperature when the combustion piston. From that analysis showed that combustion pressure has a greater role than temperature in the resulting stress on a piston *Singh et al, (2015).*

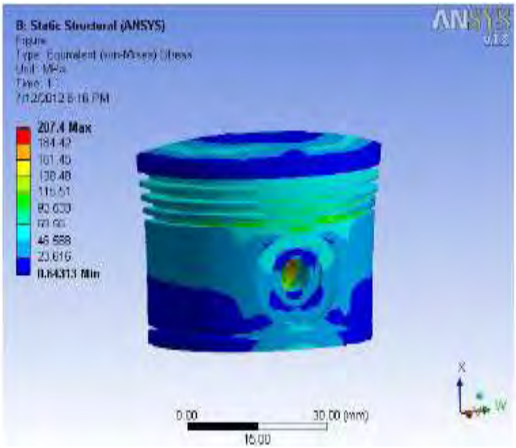

Figure 2. 6 Total Von Misses Stress Distribution Piston
(Source:Singh et al. 2015)

2.5 Finite Element Analysis

Piston and connecting rod are components in diesel engine that received load from pressure during combustion and temperature during combustion. Piston and connecting rod distributed load became mechanical energy diesel engine. Influenced of pressure and thermal load in piston are also impact to the stress distribution of the piston. Finite element analysis commonly used for analysis stress of the components depend on input load into component.

Finite element method are commonly used for thermal Analysis. Due to the complicated working environment for the piston; on one hand, the FEA for the piston became more difficult, on the other hand, though there have many methods which are put forward to apply optimal design, the optimal parameters is not easy to determine. In this study, the piston is used in low idle and rated speed gas engine. In order to enhance the engine dynamic and economic, it is necessary for the piston to implement optimization *Bhagat et al. (2013).*

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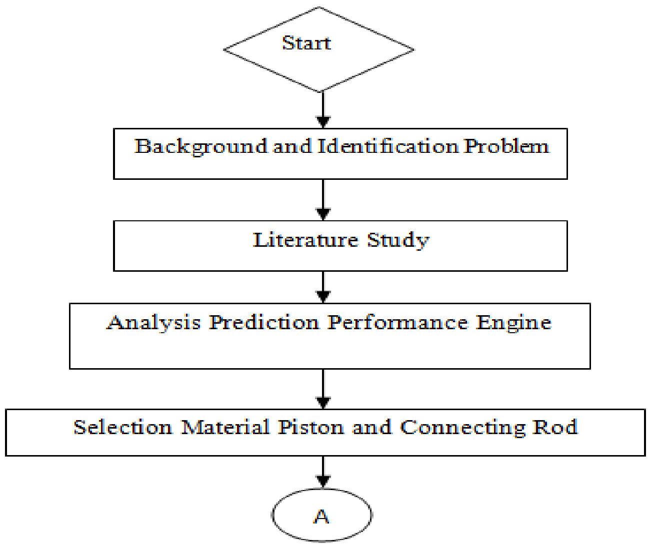
CHAPTER III
METHODOLOGY

In this chapter analysis of stress using various material selection caused by the combustion pressure that effect mechanical stress combustion temperature on the piston that effect thermal stress, coupled pressure and temperature piston during combustion that effect thermo mechanical stress. Also connecting rod stress using combinations material piston and material connecting rod. In this research bachelor thesis needs to determine how this thesis procedure done. Flow Chart diagram can be seen in Figure 3.1 below.



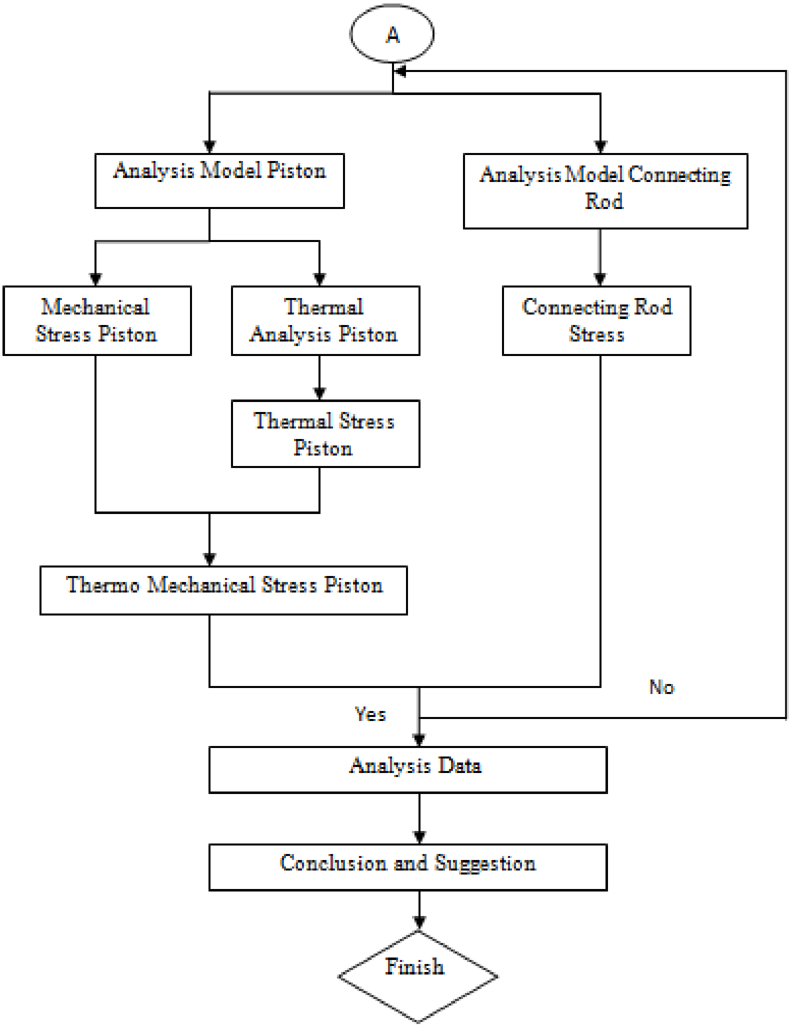


Figure 3. 1 Flowchart Methodology

3.1 Analysis Prediction Performance Engine

From the analysis simulation prediction performance obtained the following results. As well as from the results of the data obtained supporting performance prediction for input on simulation stress of piston and connecting rod. Here are some data from prediction simulation engine performance.

Table 3. 1General Data Engine

Engine Configuration	Semi Free Piston
Bore	53 mm
Stroke	60 mm
Compresion Ratio	1:21
Number of Cylinders	2
Rated Power	9.3 kW @4200 Rpm
Cooling System	Air

Table 3. 2 Input Data Stress Analysis

Pressure Maximum Piston	118.609 Bar
Pressure Minimum Piston	1.378 Bar
Temperature Combustion	1704.45 °C
Temperature Piston Crown	590K
Heat Flow	1208.37 W
Convective Heat Transfer Piston Ring Coefficient	0.00542 W/m^2. °C
Convective Heat Transfer Piston Piston Skirt	0.000322 W/m^2. °C

3.2 Selection Material

In this research using several materials selected. Material selected are for piston system stress anaysis components semi free dual piston are piston, piston pin, piston pin bearing, piston ring, and connecting rod.

3.2.1 Material Piston Data

In this research using four piston material as follows Alsi 12 CuNiMg, Alumunium A 2618, Alumunium A 4032, and AL GHS 1300.In finite element analysis for input material data required some data properties.

Table 3. 3 Properties Material Alsi 12 CuNiMg

Selected Material	Alsi 12 CuNiMg
Density	2680 kg/m^3
Young Modulus	80 Gpa
Poison Ratio	0.35
Tensile Yield Strength	340 Mpa
Compresive Yield Strength	340 Mpa
Tensile Ultimate Strength	370 Mpa
Thermal Conductivity	158 W/mc
Coefficient Thermal Expansion	0.0000206 c^{-1}

Table 3. 4 Properties Material Alumunium A 2618

Selected Material	Alumunium A 2618
Density	2768 kg/m^3
Young Modulus	73.7 Gpa
Poison Ratio	0.35
Tensile Yield Strength	420 Mpa
Compresive Yield Strength	410 Mpa
Tensile Ultimate Strength	480 Mpa
Thermal Conductivity	147 W/mc
Coefficient Thermal Expansion	0.0000259 c^{-1}

Table 3. 5 Properties Material Alumunium A 4032

Selected Material	Alumunium A 4032
Density	2685 kg/m^3
Young Modulus	79 Gpa
Poison Ratio	0.33
Tensile Yield Strength	315 Mpa
Compresive Yield Strength	320 Mpa
Tensile Ultimate Strength	380 Mpa
Thermal Conductivity	154 W/mc
Coefficient Thermal Expansion	0.0000192 c^{-1}

Table 3. 6 Properties Material AL GHS 1300

Selected Material	AL GHS 1300
Density	2780 kg/m^3
Young Modulus	98 Gpa
Poison Ratio	0.3
Tensile Yield Strength	1220 Mpa
Compresive Yield Strength	1220 Mpa
Tensile Ultimate Strength	1300 Mpa
Thermal Conductivity	120 W/mc
Coefficient Thermal Expansion	0.000018 c^{-1}

3.2.2 Piston Pin Material Data

In this research using piston pin material as follows Alsi 4140. For input material data will require some data properties. Table 3.7 show properties material Alsi 4140.

Table 3. 7 Properties Material Alsi 4140

Selected Material	Alsi 4140
Density	7850kg/m^3
Young Modulus	190 Gpa
Poison Ratio	0.27
Tensile Yield Strength	415 Mpa
Compresive Yield Strength	415 Mpa
Tensile Ultimate Strength	655 Mpa

3.2.3 Piston Pin Bearing Material Data

In this research using piston pin material as follows Alsi 7075. For input material data will require some data properties. In table3.8 general material data required properties.

Table 3. 8 Properties Material Alsi 7075

Selected Material	Alsi 7075
Density	2810
Young Modulus	98 Gpa
Poison Ratio	0.3
Tensile Yield Strength	503 Mpa
Compresive Yield Strength	503 Mpa
Tensile Ultimate Strength	572 Mpa
Thermal Conductivity	130 W/mc

3.2.4 Piston Ring Material Data

In this research using piston pin material as follow iron ductile. For input material data will require some data properties. In table 3.9 below show usgeneral material data required properties.

Table 3. 9 Properties Material Iron Ductile

Selected Material	Iron Ductile
Density	7100
Young Modulus	121 GPa
Poison Ratio	0.31
Tensile Yield Strength	551 Mpa
Compresive Yield Strength	861 Mpa
Tensile Ultimate Strength	861 Mpa
Thermal Conductivity	130 W/mc

3.2.5 Connecting Rod Material Data

In this research using two material connecting rod as follows C-70 and Alsi 1045. For input material data will require some data properties. Table 3.10 show properties material C-70 and table 3.11 show properties material Alsi 1045.

Table 3. 10 Properties Material C-70

Selected Material	C-70
Density	130 kg/m^3
Young Modulus	212 Gpa
Poison Ratio	0.29
Tensile Yield Strength	574 Mpa
Compresive Yield Strength	574 Mpa
Tensile Ultimate Strength	966 Mpa

Table 3. 11 Properties Material Alsi 1045

Selected Material	Alsi 1045
Density	789 kg/m^3
Young Modulus	200 Gpa
Poison Ratio	0.29
Tensile Yield Strength	310 Mpa
Compresive Yield Strength	310 Mpa
Tensile Ultimate Strength	565 Mpa

3.3 Analysis model Piston

In analysis three dimension model will be done meshing process, input load on the piston and connecting rod. Load input was from analysis prediction performance result. Load will input are pressure maximum during combustion, pressure, temperature piston, coefficient convective heat transfer piston, and support for piston and connecting rod. Model piston and connecting rod will analyzed steady state where pressure and temperature do not change with time.

3.3.1 Engineering Data Input

Before process analysis simulation stress, needed input data material used for process analysis stress. In generally data material needed are used as follows:

- Density (kg/m^3)
- Modulus Elasticity (Pa)
- Poison Ratio
- Tensile Yield Strength Material (Pa)
- CompresiveYield Strength Material (Pa)

- Tensile Ultimate Strength Material (Pa)
- Thermal Conductivity (W/m.C)
- Thermal Expansion Coefficient (c^{-1})

3.3.2 Meshing

Results of the piston design which has been made previously could not immediately be simulated using the finite element simulation. Before the simulation is done on a first meshing geometry, meshing understanding is the process of dividing the geometry to be analyzed into small elements. Tetrahedrons, this mesh type has six nodes, mesh of this type is enough accurate in the calculation in three dimension geometry. Because have six nodes six points for the model.For simulation model in this research using meshing type tetrahedral. Because meshing type tetrahedral more simple on process iteration. Meshing geometry specification as follow as:

Table 3. 12 Data Mesh Piston

Relevance Centre	Coarse
Element Size	Default
Smoothing	Fast
Transition	Slow
Span Angle Centre	Coarse
Minimum Edge Length	0.151230 mm

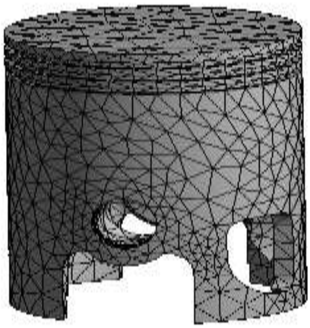


Figure 3. 2 Design Piston After Mesh Model

3.3.3 Input Pressure

In this stage purposed for input data pressure load received by piston. From prediction performance semi free piston two stroke diesel engine dual opposite obtained maximum cylinder pressure during combustion. Input pressure give into piston crown area 118.609 bar.

Figure 3. 3 Input Boundary Pressure Piston

3.3.4Input Support

In this chapter pin support piston purposed for give resistance for supporting load received by piston. Elastic support used in this analyzed because piston are not static where give pressure load or temperature load. Elastic support give for supporting based on yield material.

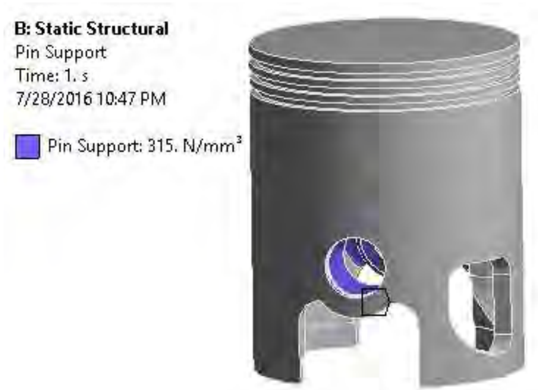


Figure 3. 4 Input Support Model Piston

3.3.5 Boundary Temperature

For obtained thermal stress or stress caused by temperature necessary to analyzed simulation thermal distribution occurs in piston, where in this simulation purposed obtained temperature distribution influenced into thermal stress of material piston. So in this stage necessary to input boundary temperature of piston crown. From analysis prediction performance obtained temperature area of piston crown are 590 K. In simulation model 3D piston temperature of piston input into piston crown area. Input boundary temperature also input boundary temperature cylinder liner 450 K as environment temperature on temperature distribution

.

Figure 3. 5 Input Boundry Temperature Piston Crown

3.3.6 Boundary Convection

In this process stage input boundary coefficient convection are in piston ring and piston skirt for heat transfer on piston. Heat transfer rate obtained from simulation prediction performance in piston ring area was 1208.37 watt, area of piston ring 703.11mm^2, and temperature condition piston crown area 316.85°C. Table 3.13 show result coefficient convection piston ring area from calculation heat transfer rate piston ring , area piston ring and temperature of piston. Figure 3.6 show input boundary convection of piston ring in model piston.

Table 3. 13 Coefficient Convection Piston Ring Area

Heat Transfer Rate Piston Ring (Watt)	1208.37
Area Piston Ring (mm^2)	703.11
Temperature Piston (°C)	316.85
Area x Temperature	222780.4035
Coefficient Convection (W/mm^2.C)	0.00542

Figure 3. 6 Input Boundary Convetion Piston Ring Area

Table 3.14 show coefficient convection piston skirt calculation. Heat transfer rate obtained from simulation prediction performance in piston ring area was 769.899 watt, area of piston skirt 7552.03mm^2, and temperature condition piston crown area 316.85°C. Figure 3.7 show input boundary convection of piston skirt in model piston.

Table 3. 14 Coefficient Convection Piston Skirt Area

Heat Transfer Rate Piston Skirt (Watt)	769.899
Area Piston Skirt (mm^2)	7552.03
Temperature Piston (°C)	316.85
Area x Temperature	2392860.706
Coefficient Convection (W/mm^2.C)	0.000322

Figure 3. 7Input Boundary Convection Piston

3.4 Mechanical Stress Analysis

Mechanical stress simulation caused by pressure maximum during combustion. Result simulation mechanical stress are figure three dimension coloured. Where coloured in simulation are stress distribution occur in model. Based on result prediction performance pressure maximum combustion is 118.609bar. More complete analysis will discuss in next chapter.

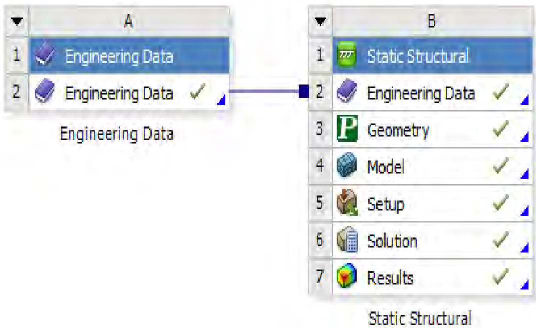


Figure 3. 8 Mechanical Stress Project Schematic

3.5 Thermal Distribution

Simulation thermal distribution piston used for input in thermal stress analysis. Input analyzed for thermal distribution piston are temperature on piston crown area, coefficient convection piston ring, piston skirt, and heat flow during combustion. Result simulation thermal distribution piston are 3D model distribution temperature and heat flux occurs on the piston.

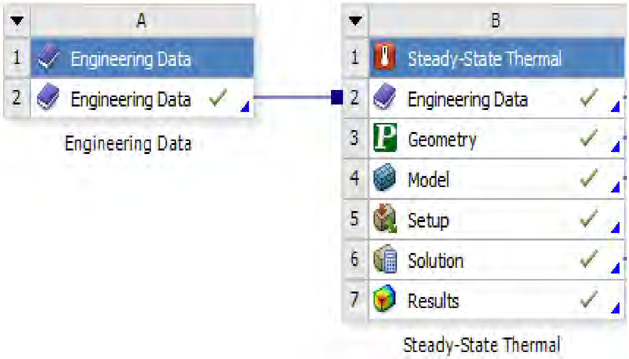


Figure 3. 9 Thermal Distribution Project Schematic

3.6 Thermal Stress Analysis

Simulation thermal stress purposed for knowing thermal stress occurs in piston caused by temperature distribution of piston and material selection. From temperature distribution analysis was imported to static structural analysis for analysis thermal stress in piston.

Figure 3. 10 Thermal Stress Project Schematic

3.7 Thermo Mechanical Stress Analysis

Thermo Mechanical stress is the combined result of the stress caused by temperature and pressure. After the simulated individually, at this stage will be a simulation involving temperature and pressure. For more details will be explained in the next chapter.

Figure 3. 11 Thermo Mechanical Stress Project Schematic

3.8 Analysis Model Connecting Rod Stress

In the analysis of stress on the connecting rod used input maximum pressure on the first piston engine and a minimum pressure on the second piston combustion process. Assumed in the stress analysis on connecting rod analysis by the pressure load. For analyzed stress connecting rod it is necessary to analyzed stress distribution of semi-free piston two-stroke diesel engine dual opposite. Analysis model of connecting rod material made with a combinations piston , piston pin, piston pin bearing, piston ring and connecting rod.

3.8.1 Contact Geometry Semi Free Piston

In this stage, the process of connecting the contact between the geometry to the design of semi-free piston to connect one component to another components. Figure 3.12 show component contact geometry connecting rod components bearing pin piston to connecting rod.

Figure 3. 12 Contact geometry connecting rod

3.8.2 Meshing Semi Free Dual Piston

Meshing of design piston and connecting rod must have same data. Because meshing influenced into analyzed stress from element of design and node. From simulation analysis used data mesh table below.

Table 3. 15 Data Mesh Semi Free Dual Piston

Relevance Centre	Coarse
Element Size	Default
Smoothing	Fast
Transition	Slow
Span Angle Centre	Coarse
Minimum Edge Length	0.151230 mm

Figure 3. 13 Design Semi Free Dual Piston After Mesh

3.8.3 Input Pressure Semi Free Dual Piston

In this stage purposed as a pressure load input received by the input pressure piston was given to the first piston and the second piston. At first piston pressure input given maximum combustion pressure of 118.609 bar while in the second piston is given a pressure of 1.378 bar.

Figure 3. 14 Input Pressure Semi Free Dual Piston

3.8.4Input Support Semi Free Piston

In this stage pin support piston purposed for give resistance for supporting load received by piston. Elastic support used in this analyzed because piston are not static where give pressure load or temperature load. Elastic support type give for supporting based on yield material.

Figure 3. 15 Input Support Semi Free Dual Piston

3.8.5 Connecting Rod Stress

At the stage of the connecting rod stress analysis was done by used analysis of mechanical stress. Analysis of the connecting rod is assumed to pressure loading without using thermal load of the combustion process. From the analysis by combination piston and connecting rod to determine the stress distribution. After analysis semi free dual piston stress are known, hide other components in addition to know the stress connecting rod that occurs.

CHAPTER IV
DATA ANALYSIS

In this following chapter explained the simulation results of analysis stress on piston and connecting rodpressure. Thermal stress of piston as a result of temperature distribution, Thermo mechanical stress of piston . Connecting rod stress analysis by distribution mechanical stress on semi free dual piston. In this research are used piston material selectedAlsi 12 CuNiMg, Aluminum A 2618, Aluminum A 4032, and AL GHS 1300. Connecting rod material selectedAlsi 1045 and C-70. Piston pin material selected Alsi 4140, bearing pin piston Alumunium A 7075 and piston ring material Iron Ductile.

4.1 Mechanical Stress of Piston

4.1.1 Material Alsi 12 CuNiMg

Figure 4.1 show the result simulation of mechanical stress on the piston by using materials Alsi 12 CuNiMg. In accordance with the input load maximum pressure during combustion 118.609 bar. Stress distribution of piston obtained maximum stress value was 248.71MPa and the minimum stress value 0.26979 MPa. The largest mechanical stress piston using material Alsi 12 CuNiMg was occurred in the section inner piston and wrist pin are as indicated by the red arrows.

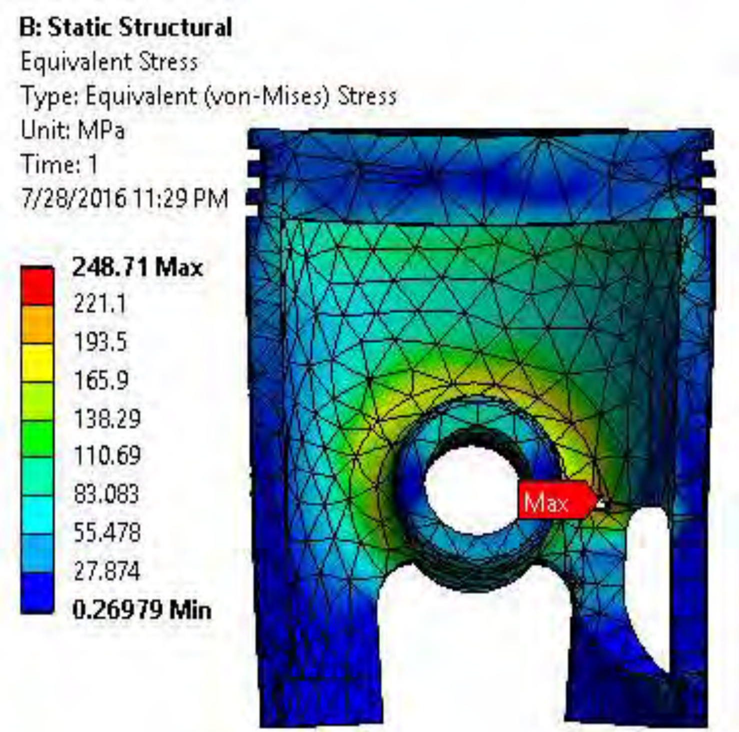


Figure 4. 1 Mechanical Stress of Piston Material Alsi 12 CuNiMg On Section View

Figure 4.2 show the result of mechanical deformation stress on the piston by using materials Alsi 12 CuNiMg. From the analysis of the stress distribution maximum stress 248.71 Mpa and minimum stress value of 0.26979 MPa. Largest deformations was occur in piston crown area. Obtained intensity deformations maximum 0.16057 mm and minimum deformations 0.041253 mm.

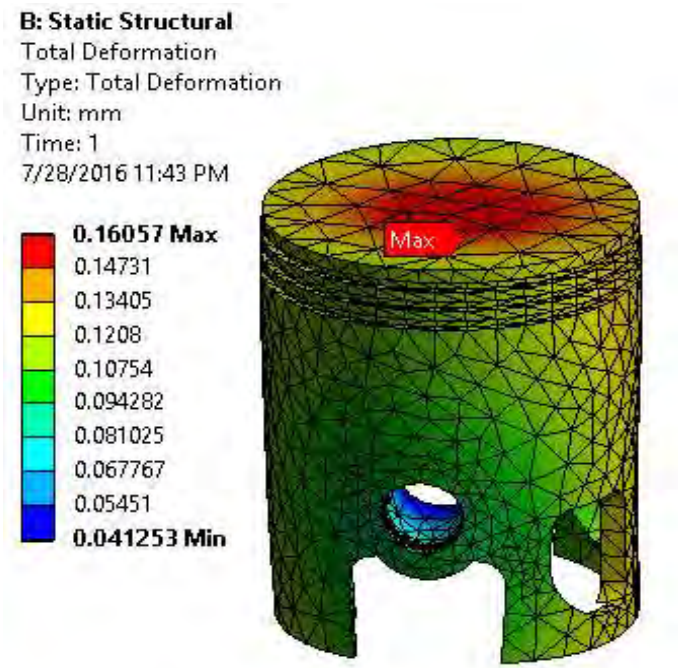


Figure 4. 2 Deformation Mechanical Stress of Piston Material Alsi 12 CuNiMg

4.1.2 Material Alumunium A 2618

Figure 4.3 show the result simulation of mechanical stress on the piston by used material Alumunium A 2618. In accordance with the input load maximum pressure during combustion 118.609 bar. Stress distribution of piston obtained maximum stress value was 229.6 MPa and the minimum stress value 0.36602 MPa. The largest mechanical stress piston using material Alumunium A 2618 was occurred in thesection inner piston and wrist pin are as indicated by the red arrows.

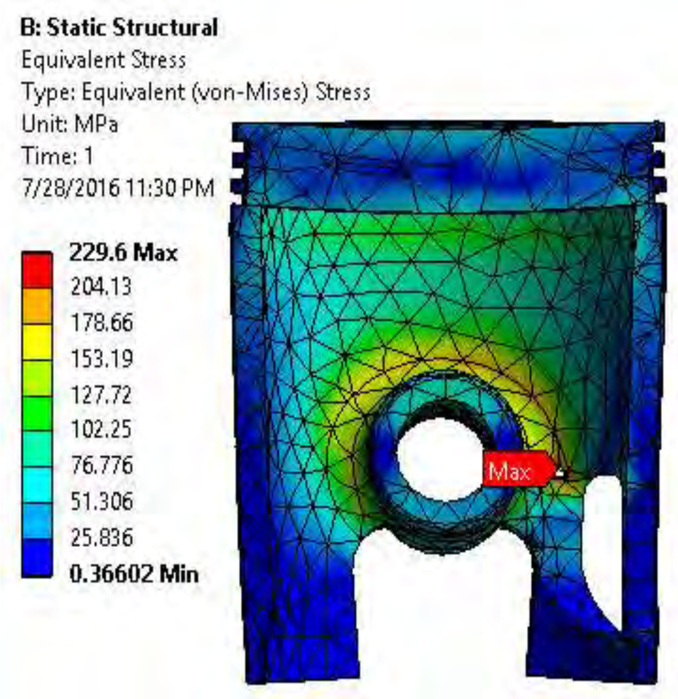


Figure 4. 3 Mechanical Stress of Piston Material Alumunium A 2618 On Section View

Figure 4.4 show the result of mechanical deformation stress on the piston by using material Alumunium A 2618. From the analysis of the stress distribution maximum stress 229.6 MPa and minimum stress value of 0.366 MPa. Largest deformations was occur in piston crown area. Obtained intensity maximum deformation 0.15411 mm and minimum deformation 0.030519 mm.

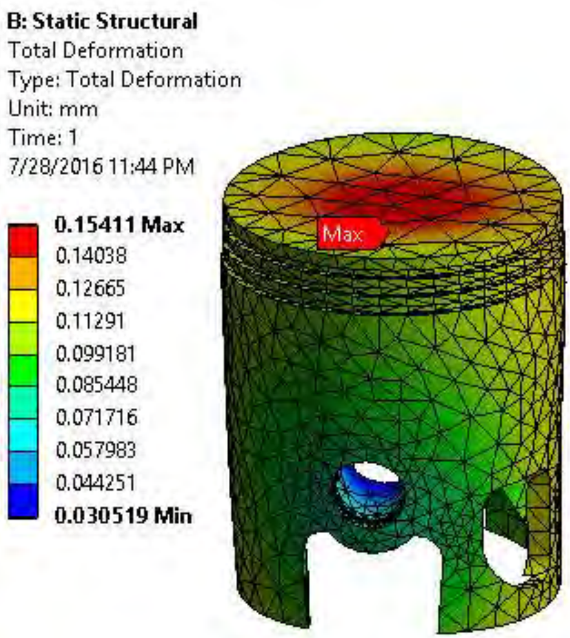


Figure 4. 4 Deformation Mechanical Stress of Piston Material Alumunium A 2618

4.1.3 Material Alumunium A 4032

Figure 4.5 show the result simulation of mechanical stress on the piston by used material Alumunium A 4032. In accordance with the input load maximum pressure during combustion 118.609 bar. Stress distribution of piston obtained maximum stress value was 253.51 MPa and the minimum stress value 0.25433 MPa. The largest mechanical stress piston using materialAlumunium A 4032 was occurred in the section inner piston and wrist pin are as indicated by the red arrows.

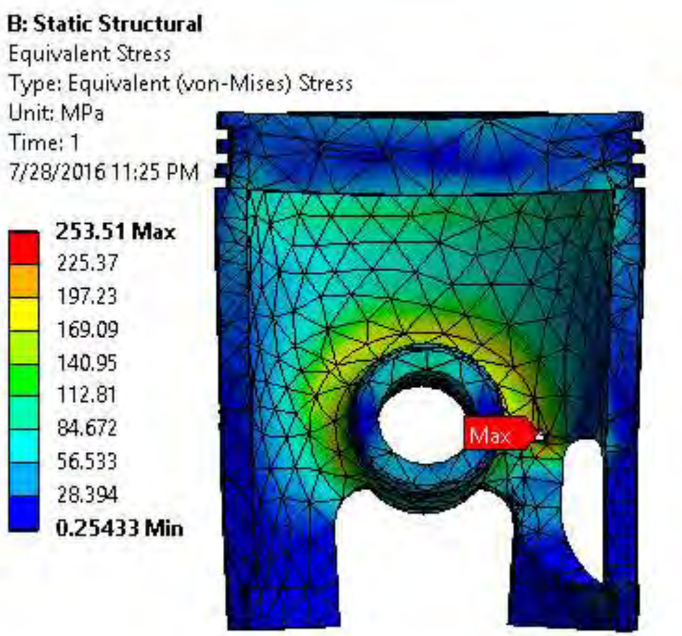


Figure 4. 5 Mechanical Stress of Piston Material A 4032 On Section view

Figure 4.6 show the result of mechanical deformation stress on the piston by using material Alumunium A 4032. From the analysis of the stress distribution maximum stress 253.51 MPa and minimum stress value of 0.2543 MPa. Largest deformations was occur in piston crown area. Obtained intensity deformations maximum 0.16751 mm and minimum deformations 0.030519 mm.

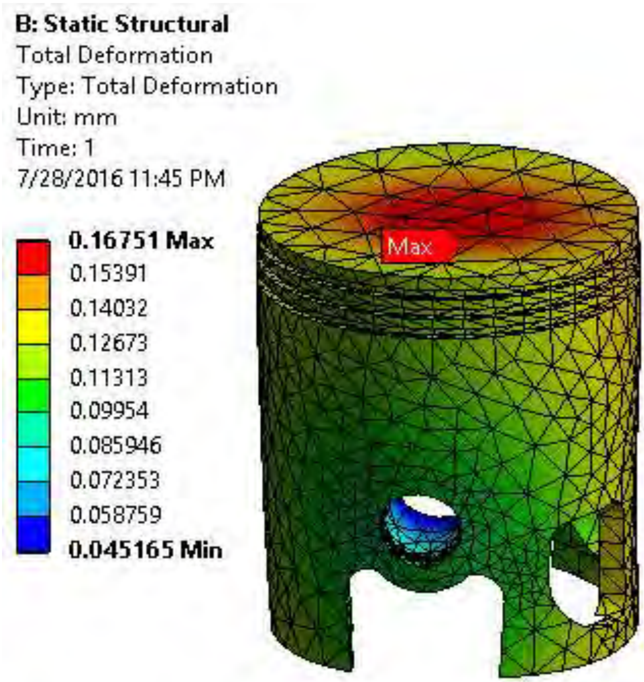


Figure 4. 6 Deformation Mechanical Stress of Piston Material Alumunium A 4032

4.1.4 Material AL GHS 1300

Figure 4.7 show the result simulation of mechanical stress on the piston by used material AL GHS 1300. In accordance with the input load maximum pressure during combustion 118.609 bar. Stress distribution of piston obtained maximum stress value was 185.52 MPa and the minimum stress value 0.32606 MPa. The largest mechanical stress piston using material AL GHS 1300 was occurred in the section inner piston and wrist pin are as indicated by the red arrows.

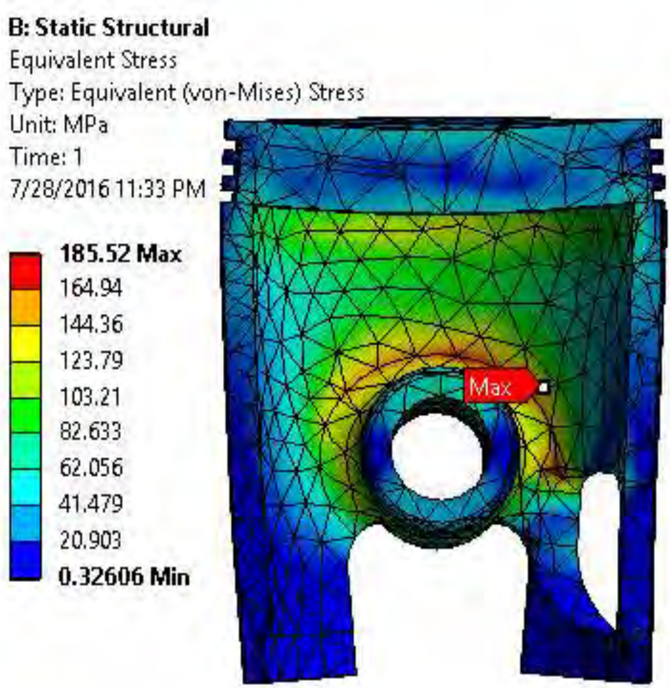


Figure 4. 7 Mechanical Stress of Piston Material AL GHS 1300 On Section view

Figure 4.8 show the result of mechanical deformation stress on the piston by using material AL GHS 1300. From the analysis of the stress distribution maximum stress 185.52 MPa and minimum stress value 0.32606 MPa. Largest deformations was occur in piston crown area. Obtained intensity deformations maximum 0.090685 mm and minimum 0.0080177 deformations mm.

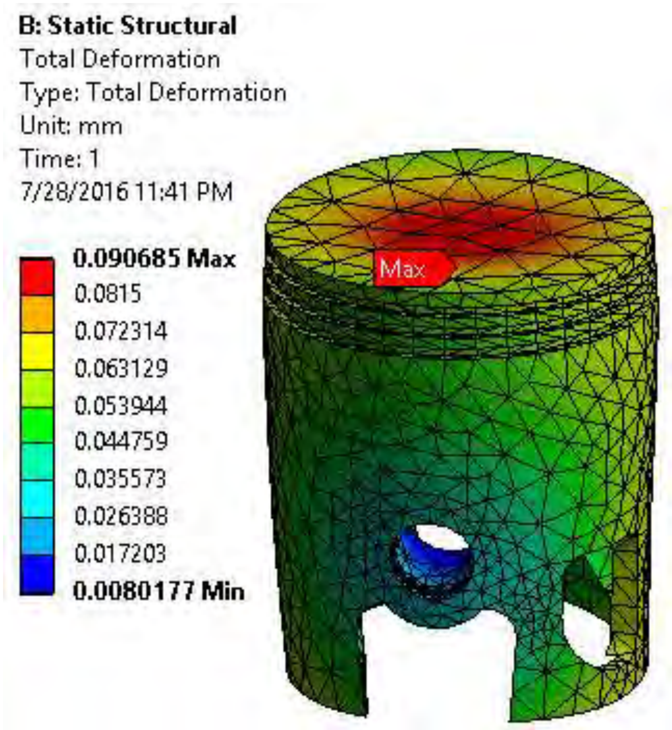


Figure 4. 8 Deformation Mechanical Stress of Piston Material AL GHS 1300

4.3 Thermal Distribution Piston

4.3.1 Material Piston Alumunium Alsi 12 CuNiMg

Figure 4.9 shows the temperature distribution in the piston material Alsi 12 CuNiMg when given temperature loads. The highest temperature 316.85 °C and lowest temperature 126.97 °C. While most Heat Flux is 2.5304 W/mm² and the lowest was 0.00135 W/mm². The temperature occurs in part because the piston crowns directly affected the combustion temperature. While the heat flux occurs largest in the piston ring due to the process of convection heat transfer piston.

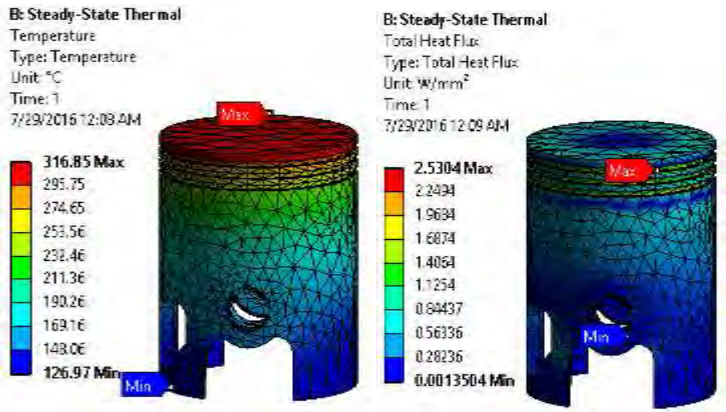


Figure 4. 9 Thermal Distribution of Material Piston Alsi 12 CuNiMg

4.3.2 Material PistonAlumunium A 2618

Figure 4.10 shows the temperature distribution in the piston material A 2618 when given temperature loads. The highest temperature 316.85 °C and lowest temperature 120.5 °C. While most Heat Flux is 2.4929 W/mm² and the lowest was 0.00131 W/mm². The temperature occurs in part because the piston crowns directly affected the combustion temperature. While the heat flux occurs largest in the piston ring due to the process of convection heat transfer piston.

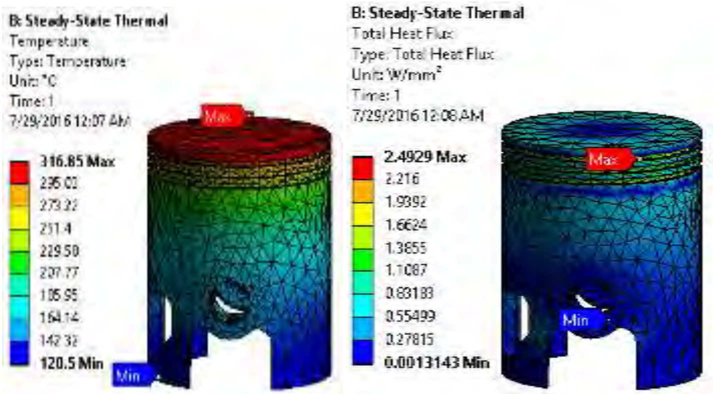


Figure 4. 10 Thermal Distribution of Material Piston A 2618

4.3.3 Material PistonAlumunium A 4032

Figure 4.11 shows the temperature distribution in the piston material A 4032 when given temperature loads. The highest temperature 316.85 °C and lowest temperature 124.66 °C. While most Heat Flux is 2.4929 W / mm² and the lowest was 0.00133 W/mm². The temperature occurs in part because the piston crowns directly affected the combustion temperature. While the heat flux occurs largest in the piston ring due to the process of convection heat transfer piston.

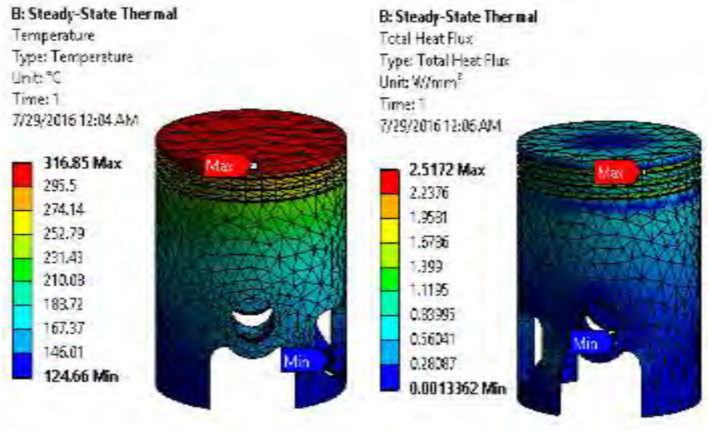


Figure 4. 11 Thermal Distribution of Material Piston A 4032

4.3.4 Material Piston AL GHS 1300

Figure 4.16 shows the temperature distribution in the piston material AL GHS 1300 when given temperature loads. The highest temperature 316.85 °C and lowest temperature 102.92 °C. While most Heat Flux is 2.3822 W/mm² and the lowest was 0.001269 W/mm². The temperature occurs in part because the piston crowns directly affected the combustion temperature. While the heat flux occurs largest in the piston ring due to the process of convection heat transfer piston.

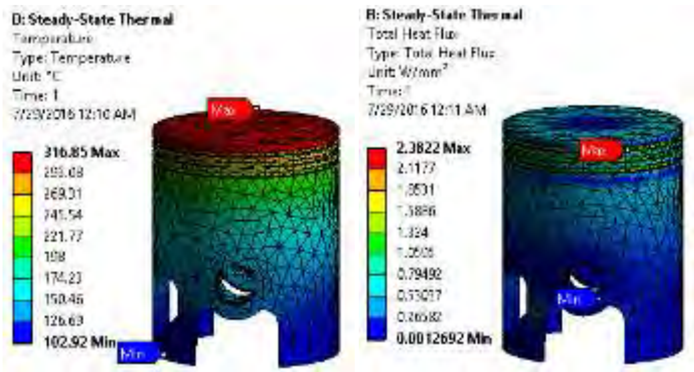


Figure 4. 12 Thermal Distribution of Material Piston AL GHS 1300

4.4 Thermal Stress Piston

4.4.1 Material PistonAlsi 12 CuNiMg

Figure 4.13 show the result simulation of thermal stress on the piston by used material Alsi 12 CuNiMg.Appropriate thermal analysis obtained temperature distribution maximum temperature of 316.85 °C and minimum temperature 126.97 °C. Thermal stress piston obtained maximum stress value was 70.655 MPa and the minimum stress value 0.14478 MPa . The largest thermal stress piston using material Alumunium A 4032 was occurred in piston ring grove area.

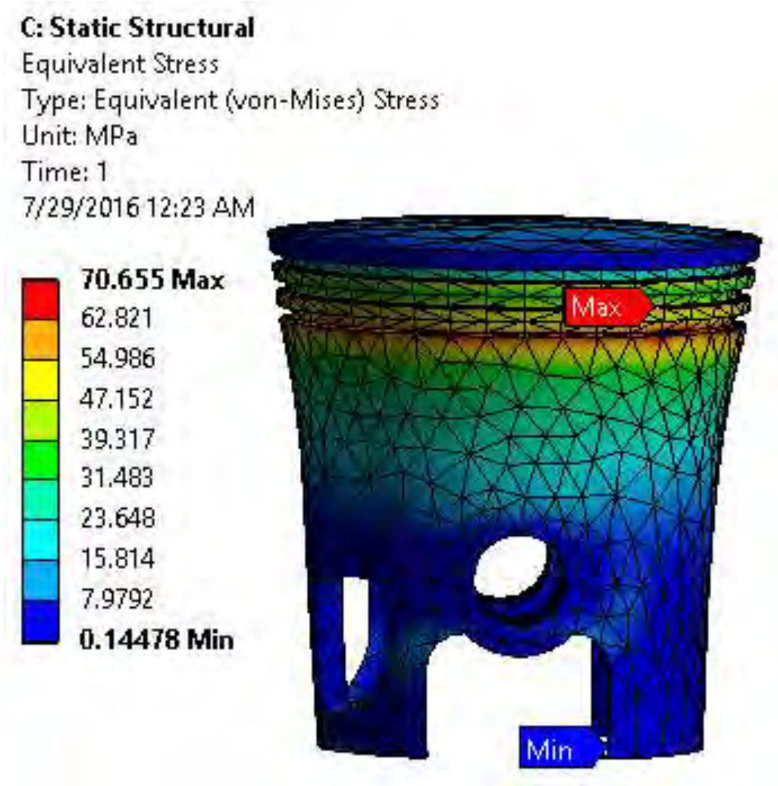


Figure 4. 13 Thermal Stress of Piston Material Alsi 12 CuNiMg

Figure 4.14 show the result of thermal stress deformation material Alsi 12 CuNiMg on the piston by using material Alsi 12 CuNiMg. From the analysis of thermal stress obtained maximum stress 70.655 MPa and minimum stress value 0.32606 MPa. Largest deformations was occur in piston crown edge area. Obtained intensity maximum deformations0.08262 mm and minimum deformations 0.000313 mm.

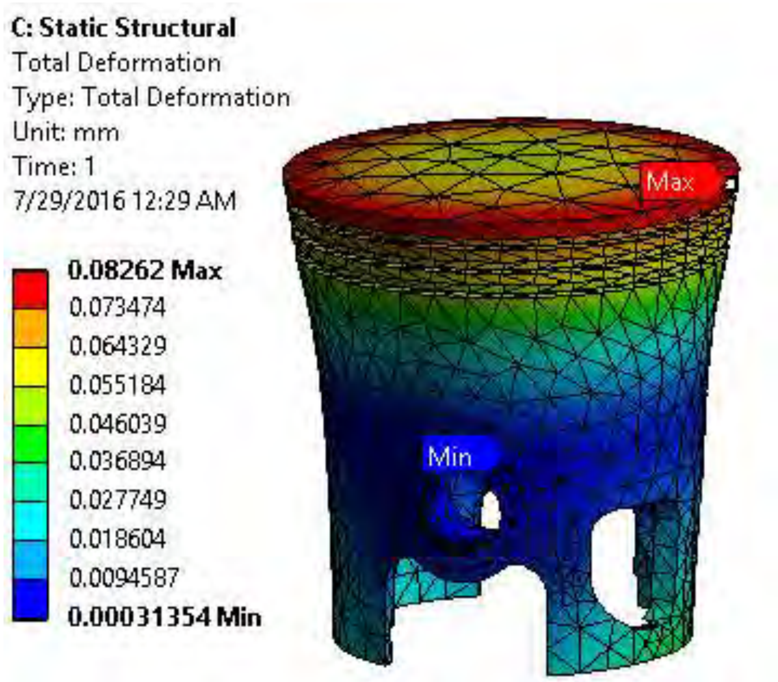


Figure 4. 14 Deformations Thermal Stress of Piston Material Alsi 12 CuNiMg

4.4.2 Material Piston Alumunium A 2618

Figure 4.15 show the result simulation of thermal stress on the piston by used material Alumunium A 2618.Appropriate thermal analysis obtained temperature distribution maximum temperature of 316.85 °C and minimum temperature 120.5 °C. Thermal stress piston obtained maximum stress value was 85.723 MPa and the minimum stress value0.155776 MPa.

The largest thermal stress piston using material Alumunium A 2618 was occurred in piston ring grove area.

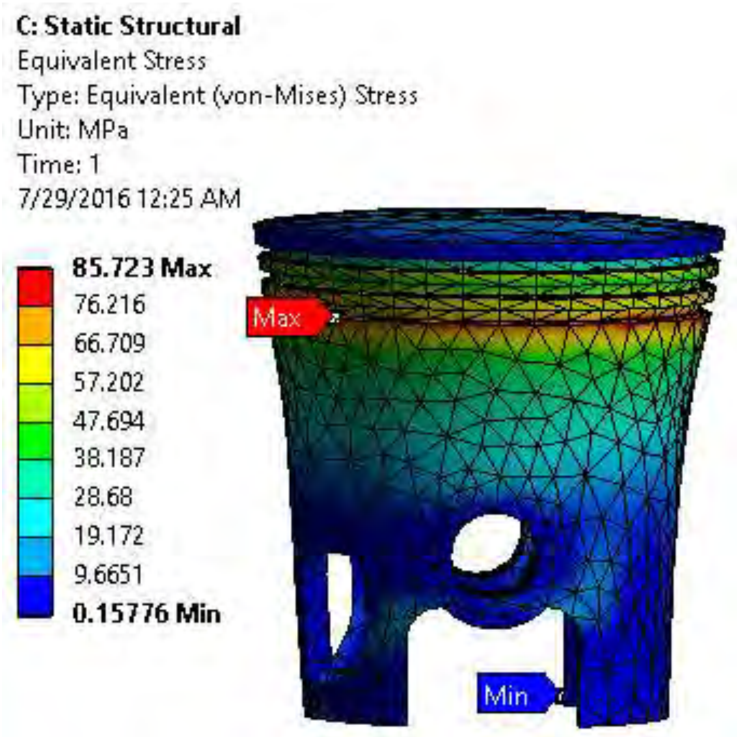


Figure 4. 15 Thermal Stress of Piston Material Alumunium A 2618

Figure 4.16 show the result of thermal stress deformation material on the piston by using material Alumunium A 2618. From the analysis of thermal stress obtained maximum stress 85.723 MPa and minimum stress value 0.15776 MPa. Largest deformations was occur in piston crown edge area. Obtained intensity maximum deformations 0.10387 mm and minimum deformations 0.0000931 mm.

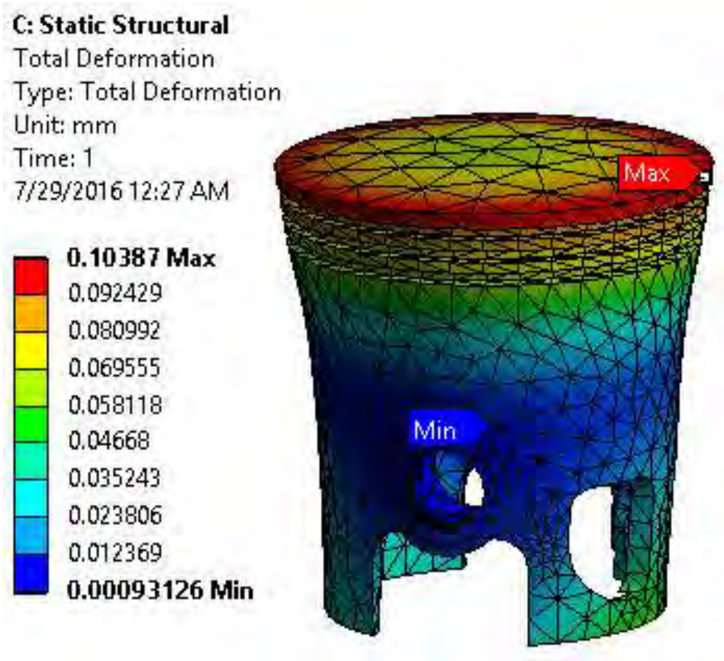


Figure 4. 16 Deformations Thermal Stress of Piston Material Alumunium A 2618

4.4.3 Material PistonAlumunium A 4032

Figure 4.17 show the result simulation of thermal stress on the piston by used material Alumunium A 4032.Appropriate thermal analysis obtained temperature distribution maximum temperature of 316.85 °C and minimum temperature 124.66 °C. Thermal stress piston obtained maximum stress value was 65.571MPaand the minimum stress value0.13075 MPa. The largest thermal stress piston using material Alumunium A 4032 was occurred in piston ring grove area.

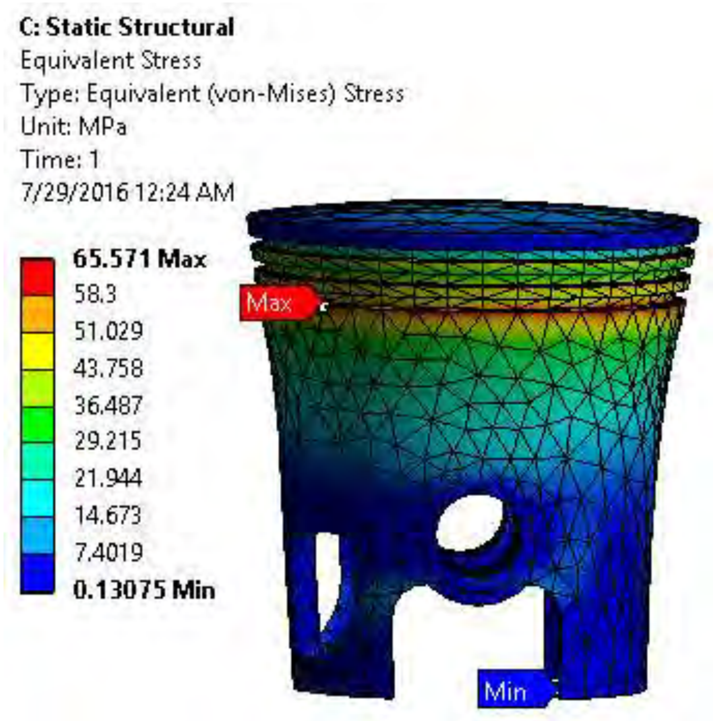


Figure 4. 17 Thermal Stress of Piston Material Alumunium A 4032

Figure 4.18 show the result of thermal stress deformation material on the piston by using material Alumunium A 4032. From the analysis of thermal stress obtained maximum stress 65.571MPa and minimum stress value

0.13075 MPa. Largest deformations was occur in piston crown edge area. Obtained intensity maximum deformation 0.076967 mm and minimum deformation 0.000309 mm.

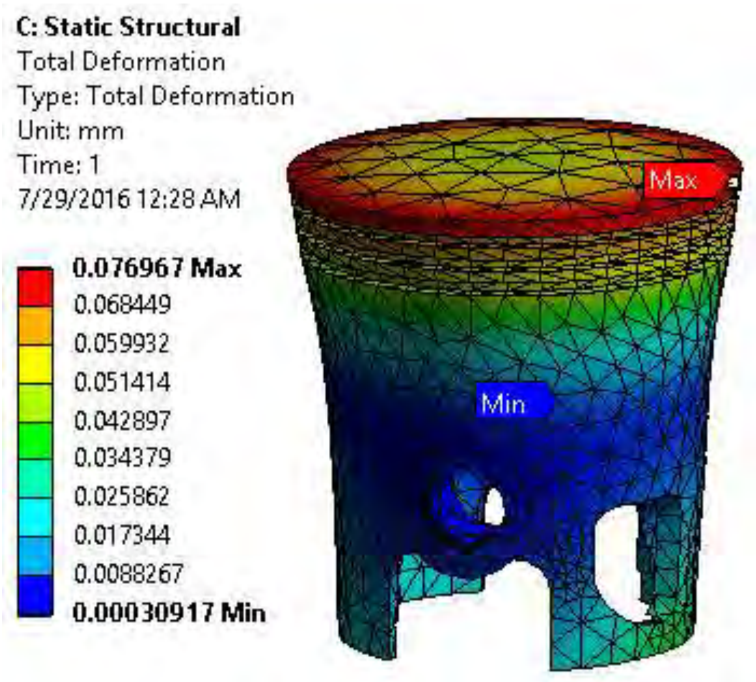


Figure 4. 18 Deformations Thermal Stress of Piston Material Alumunium A 4032

4.4.4 Material Piston AL GHS 1300

Figure 4.19 show the result simulation of thermal stress on the piston by used material AL GHS 1300.Appropriate thermal analysis obtained temperature distribution maximum temperature of 316.85 °C and minimum temperature 102.92

°C. Thermal stress piston obtained maximum stress value was 88.809 MPa and the minimum stress value 0.12464 MPa . The largest thermal stress piston using material AL GHS 1300 was occurred in piston ring grove area

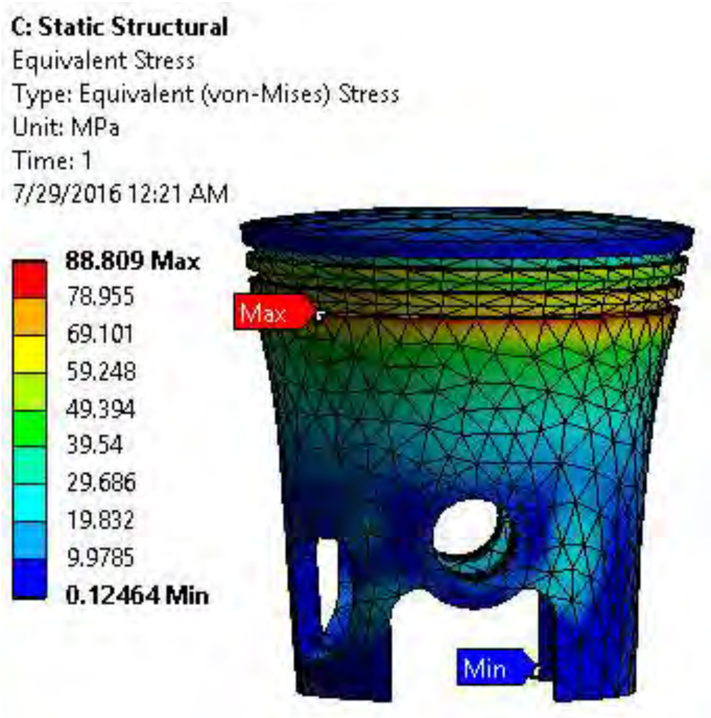


Figure 4. 19 Thermal Stress of Piston Material AL GHS 1300

Figure 4.20 show the result of thermal stress deformation material on the piston by using material AL GHS 1300. From the analysis of thermal stress obtained maximum stress 88.809 MPa and minimum stress value 0.12464 MPa. Largest deformations was occur in piston crown edge area. Obtained intensity maximum deformation 0.073533 mm and minimum deformation 0.0018506 mm.

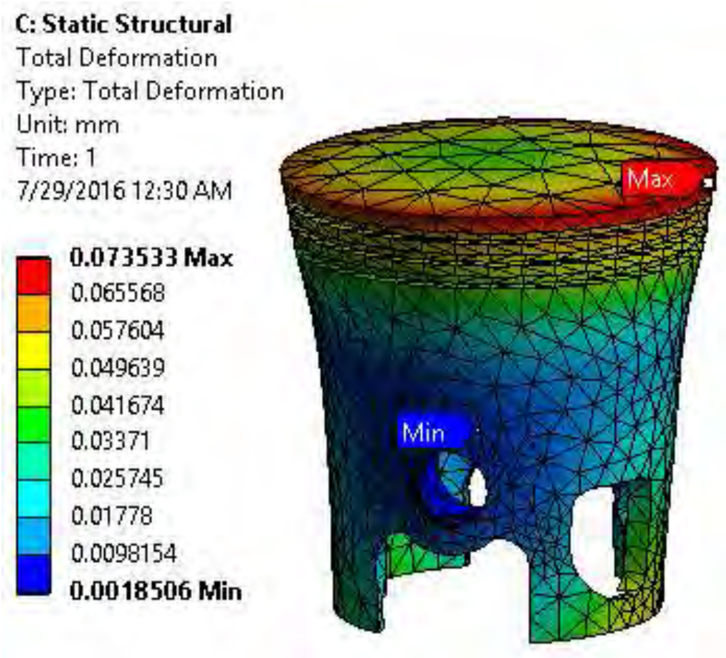


Figure 4. 20 Deformation Thermal Stress of Piston Material AL GHS 1300

4.5 Thermo Mechanical Stress Piston

4.5.1 Material PistonAlsi 12 CuNiMg

Figure 4.21 show the result simulation of thermo mechanical stress on the piston by used material Alsi 12 CuNiMg. From result mechanical maximum stress 248.71 MPa and minimum stress 0.26979 MPa. Thermal maximum stress 70.655 MPa and minimum stress 0.14478 MPa. Obtained thermo mechanical maximum stress 253.37 MPa and minimum stress 0.23807 MPa. The largest thermo mechanical maximumstress using material Alsi 12 CuNiMg was occurred in inner piston near the window area.

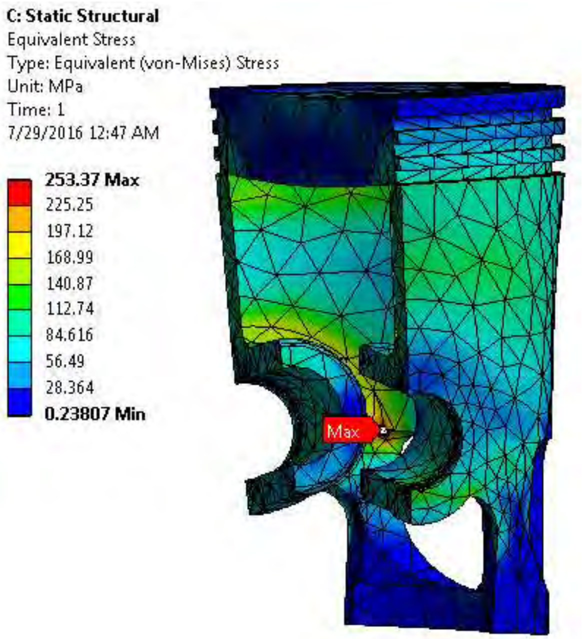


Figure 4. 21 Thermo Mechanical Stress of Piston Material Alsi 12 CuNiMg On Section View

Figure 4.22 show the result of deformation thermo mechanical stress of piston Material Alsi 12 CuNiMg. From the analysis of thermo mechanical stress obtained maximum stress 253.37 MPa and minimum stress value 0.23807 MPa. Obtained intensity maximum deformation 0.073533 mm and minimum deformation 0.0018506 mm. Largest deformation occurs in piston skirt window area.

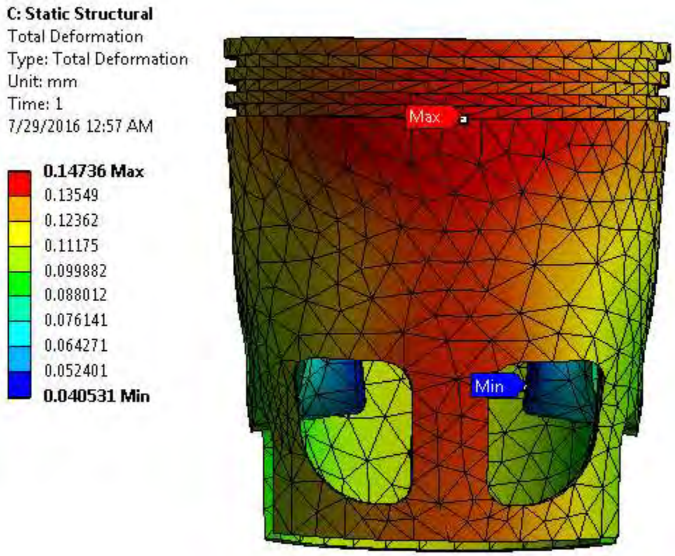


Figure 4. 22 Deformation Thermo Mechanical Stres of Piston Material Alsi 12 CuNiMg

4.5.2 Material Piston Alumunium A 2618

Figure 4.23 show the result simulation of thermo mechanical stress on the piston by used material Alumunium A 2618. From result mechanical maximum stress 229.6 MPa and minimum stress 0.36602 MPa. Thermal maximum stress 85.723 MPa and minimum stress 0.157 MPa. Obtained thermo mechanical maximum stress 236.96 MPa and minimum stress 0.29159 MPa. The largest thermo mechanical maximum stress using material Alumunium A 2618 was occurred in inner piston near the window area.

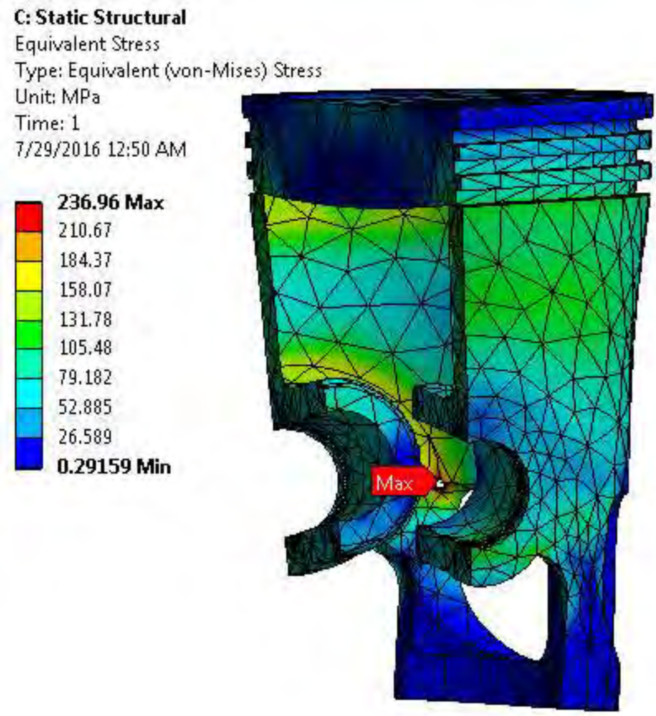


Figure 4. 23 Thermo Mechanical Stress of Piston Alumuinum A 2618 On Section View Piston

Figure 4.24 show the result of deformation thermo mechanical stress of piston Material Alumunium A 2618. From the analysis of thermo mechanical stress obtained maximum stress 236.96 MPa and minimum stress value 0.29159 MPa. Obtained intensity maximum deformation 0.14919 mm and minimum deformation 0.030561 mm. Largest deformation occurs in piston skirt window area.

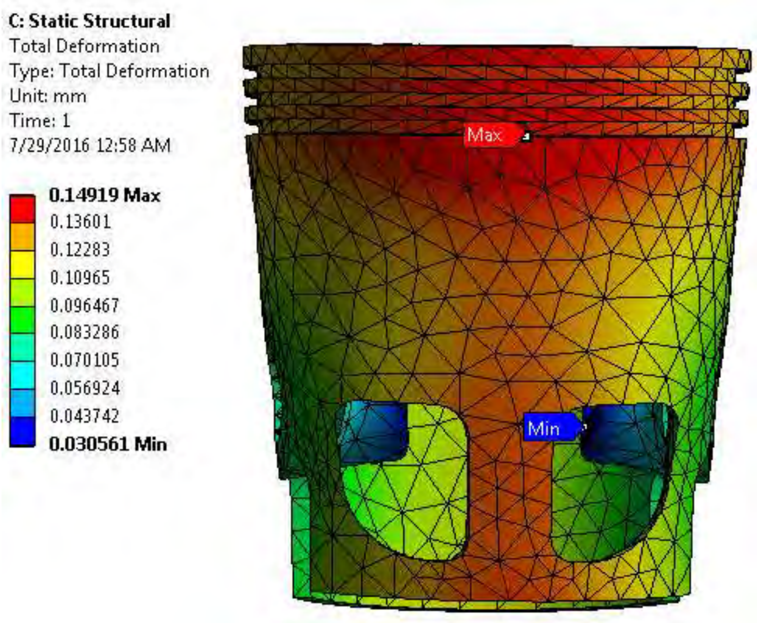


Figure 4. 24 Deformation Thermo Mechanical Stress of Piston Material Alumunium A 2618

4.5.3 Material PistonAlumunium A 4032

Figure 4.25 show the result simulation of thermo mechanical stress on the piston by used material Alumunium A 4032. From result mechanical maximum stress 253.51 MPa and minimum stress 0.25433 MPa. Thermal maximum stress 65.571 MPa and minimum stress 0.13075 MPa. Obtained thermo mechanical maximum stress 259.27 MPa and minimum stress 0.27209 MPa. The largest thermo mechanical maximum stress using material Alumunium A 2618 was occurred in inner piston near the window area.

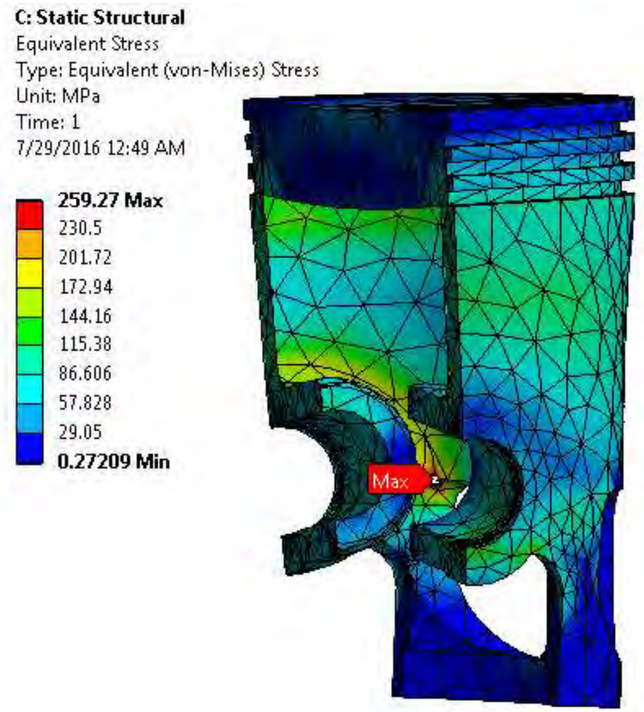


Figure 4. 25 Thermo Mechanical Stress of Piston Material Alumunium A 4032 On Section View

Figure 4.26 show the result of deformation thermo mechanical stress of piston Material Alumunium A 4032. From the analysis of thermo mechanical stress obtained maximum stress 259.27 MPa and minimum stress value 0.27209 MPa. Obtained intensity maximum deformation 0.15339 mm and minimum deformation 0.044364 mm. Largest deformation occurs in piston skirt window area.

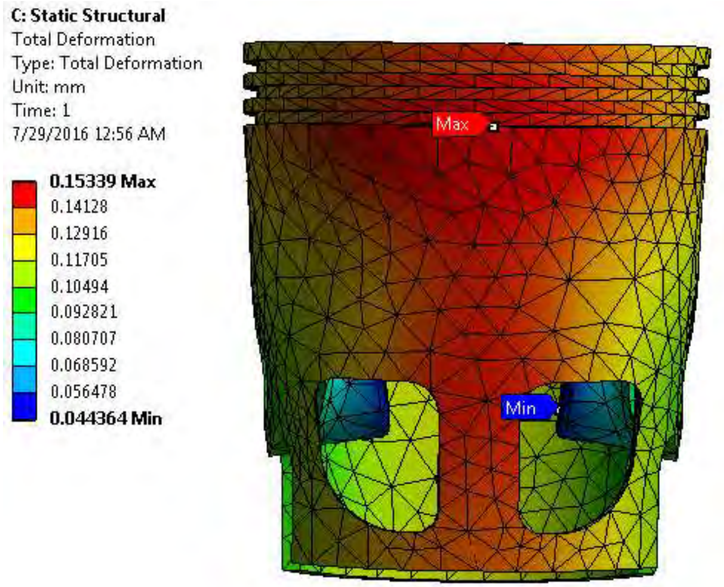


Figure 4. 26 Deformation Thermo Mechanical Stress of Piston Material Alumunium A 4032

4.5.4 Material Piston AL GHS 1300

Figure 4.27 show the result simulation of thermo mechanical stress on the piston by used material AL GHS 1300. From result mechanical maximum stress 185.52 MPa and minimum stress 0.32606 MPa. Thermal maximum stress 88.809 MPa and minimum stress 0.12464 MPa. Obtained thermo mechanical maximum stress 199.42 MPa and minimum stress 0.26023 MPa. The largest thermo mechanical maximum stress using material Alumunium AL GHS 1300 was occurred in inner piston near the window area.

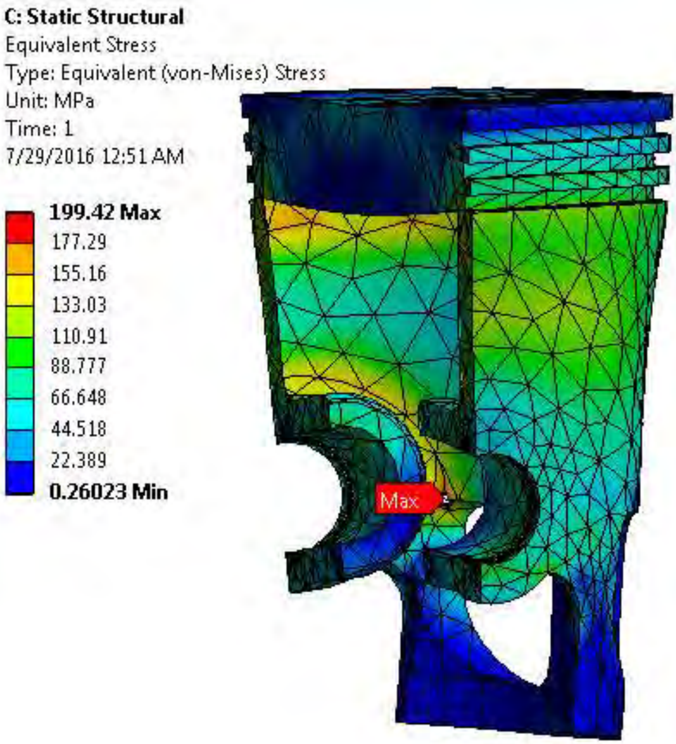


Figure 4. 27 Thermo Mechanical Stress of Piston AL GHS 1300 On Section View

Figure 4.27 show the result of deformation thermo mechanical stress of piston Material Alumunium AL GHS 1300. From the analysis of thermo mechanical stress obtained maximum stress 199.42 MPa and minimum stress value 0.26023 MPa. Obtained intensity maximum deformation 0.15339 mm and minimum deformation 0.044364 mm. Largest deformation occurs in piston skirt window area.

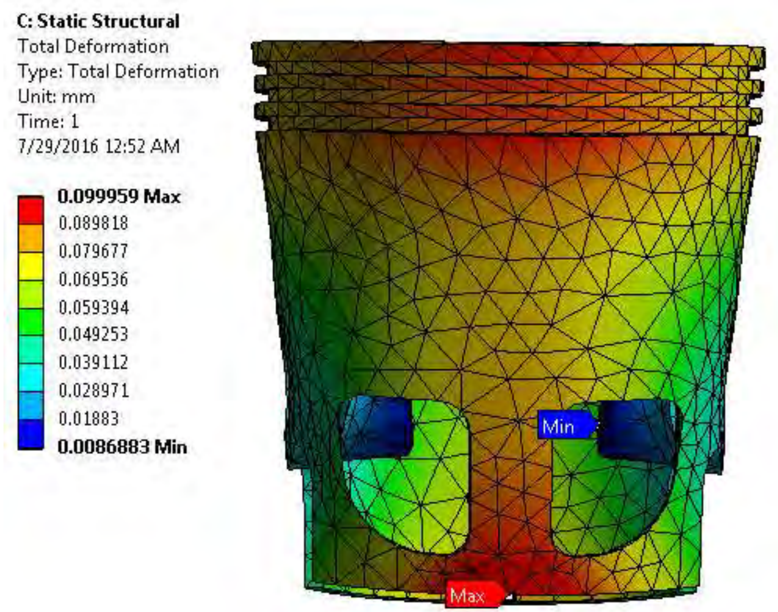


Figure 4. 28 Deformation Thermo Mechanical Stress of Piston Material Alumunium AL GHS 1300

4.6 Connecting Rod Stress

4.6.1 Connecting Rod Material Alsi 1045

Figure 4.37 show the result of the simulation semi free dual piston of stress material piston Alsi 12 CuNiMg and material connecting rod Alsi 1045. From input data pressure during combustion in 118.609 bar in cylinder one and 1.378 bar in cylinder two. Obtained stress distribution semi free dual piston maximum stress was 290.51 MPa and minimum stress value is 0.0008504MPa. From analysis greatest stress area were occured in piston pin.

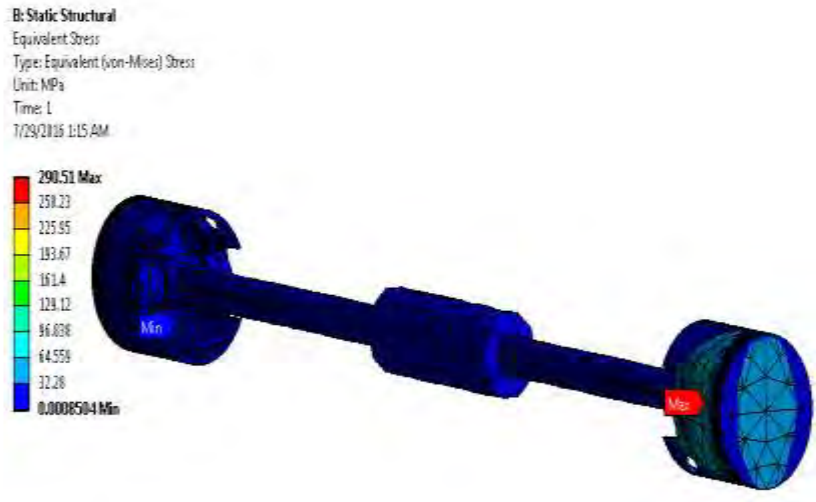


Figure 4. 29 Semi Free Dual Piston Stress Material Piston Alsi 12 CuNiMg and Material Connecting Rod Alsi 1045

Figure 4.30 show the result of the simulation of stress on connecting rod by using material piston Alsi 12 CuNiMg and material connecting rod Alsi 1045. From input data 118.609 bar in cylinder one and 1.378 bar in cylinder two distribution load from piston. Result of the stress distribution connecting rod obtained greatest value was 83.24 MPa. From analysis greatest stress area are occurs in connecting rod connection with piston pin.

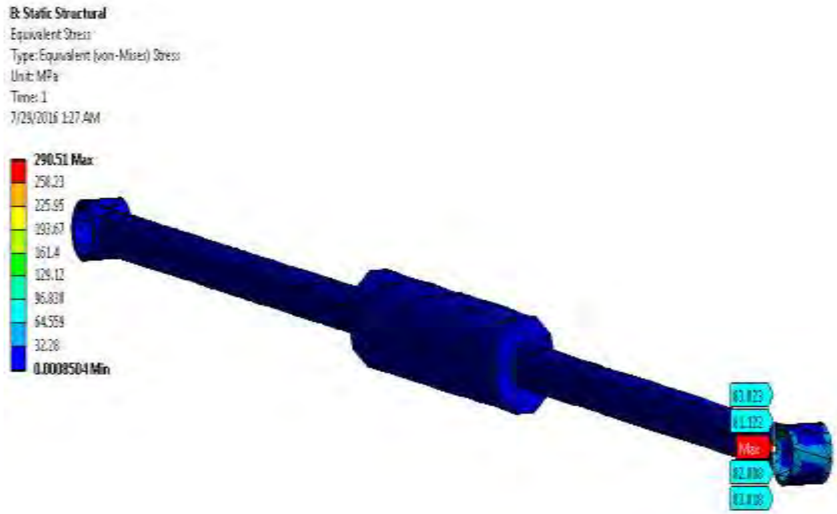


Figure 4. 30 Connecting Rod Stress Material Piston Alsi 12 CuNiMg and Material Connecting Rod Alsi 1045

Figure 4.37 show the result of the simulation semi free dual piston of stress material piston Alumunium A 2618 and material connecting rod Alsi 1045. From input data pressure during combustion in 118.609 bar in cylinder one and 1.378 bar in cylinder two. Obtained stress distribution semi free dual piston maximum stress was 286.99 MPa and minimum stress value is 0.00095622 MPa. From analysis greatest stress area were occured in piston pin.

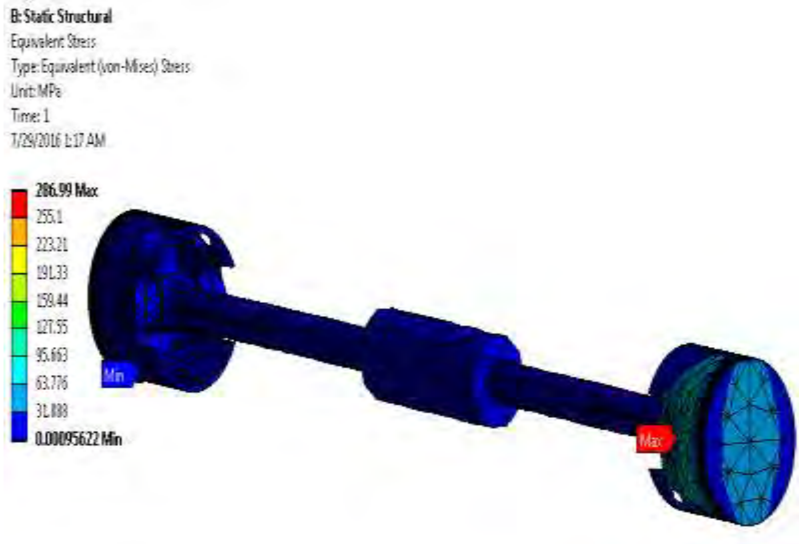


Figure 4. 31 Semi Free Dual Piston Stress Material Piston Alumunium A 2618 and Material Connecting Rod Alsi 1045

Figure 4.32 show the result of the simulation of stress on connecting rod by using material piston Alsi 12 CuNiMg and material connecting rod Alsi 1045. From input data 118.609 bar in cylinder one and 1.378 bar in cylinder two distribution load from piston. Result of the stress distribution connecting rod obtained greatest value was 67.135 MPa. From analysis greatest stress area are occurs in connecting rod connection with piston pin.

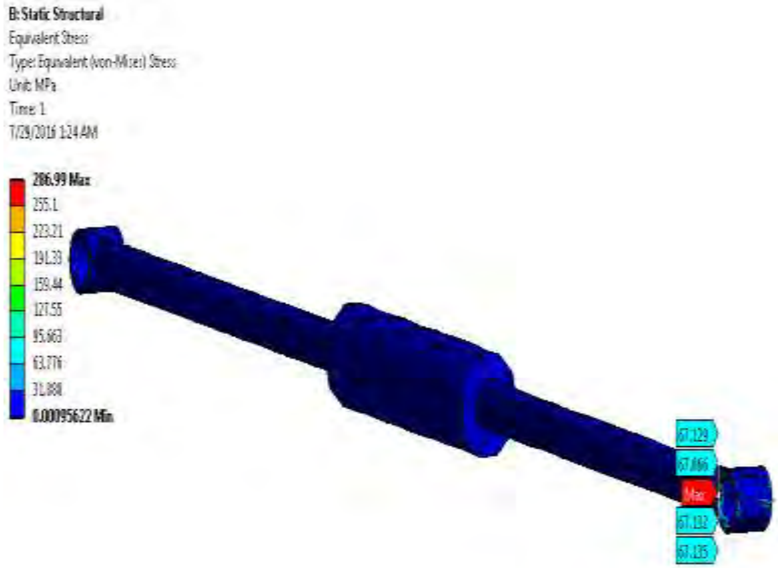


Figure 4. 32 Connecting Rod Stress Material Piston AlumuniumA 2618 and Material Connecting Rod Alsi 1045

Figure 4.33 show the result of the simulation semi free dual piston of stress material piston Alumunium A 4032 and material connecting rod Alsi 1045. From input data pressure during combustion in 118.609 bar in cylinder one and 1.378 bar in cylinder two. Obtained stress distribution semi free dual piston maximum stress was 307.15 MPa and minimum stress value is 0.00095622 MPa. From analysis greatest stress area were occured in piston pin.

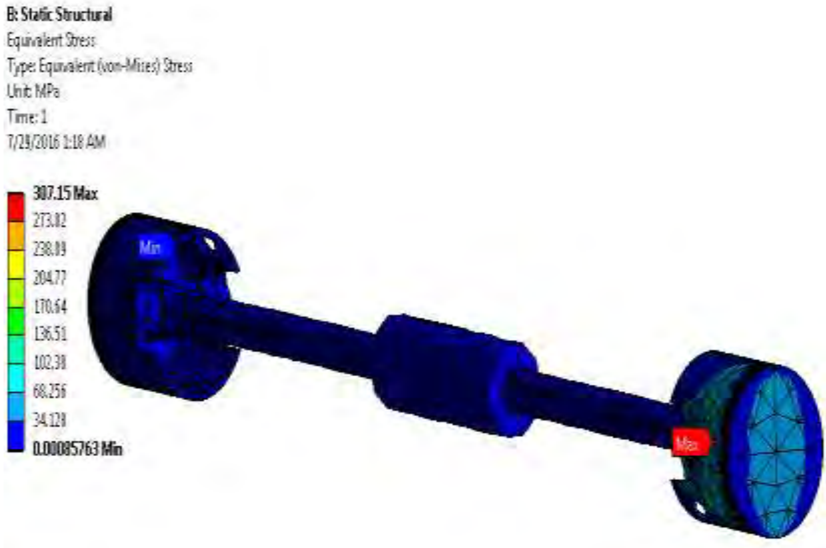


Figure 4. 33 Semi Free Dual Piston Stress Material Piston Alumunium A 4032 and Material Connecting Rod Alsi 1045

Figure 4.34 show the result of the simulation of stress on connecting rod by using material piston Alumunium A 4032 and material connecting rod Alsi 1045. From input data 118.609 bar in cylinder one and 1.378 bar in cylinder two distribution load from piston. Result of the stress distribution connecting rod obtained greatest value was 89.086 MPa. From analysis greatest stress area are occurs in connecting rod connection with piston pin.

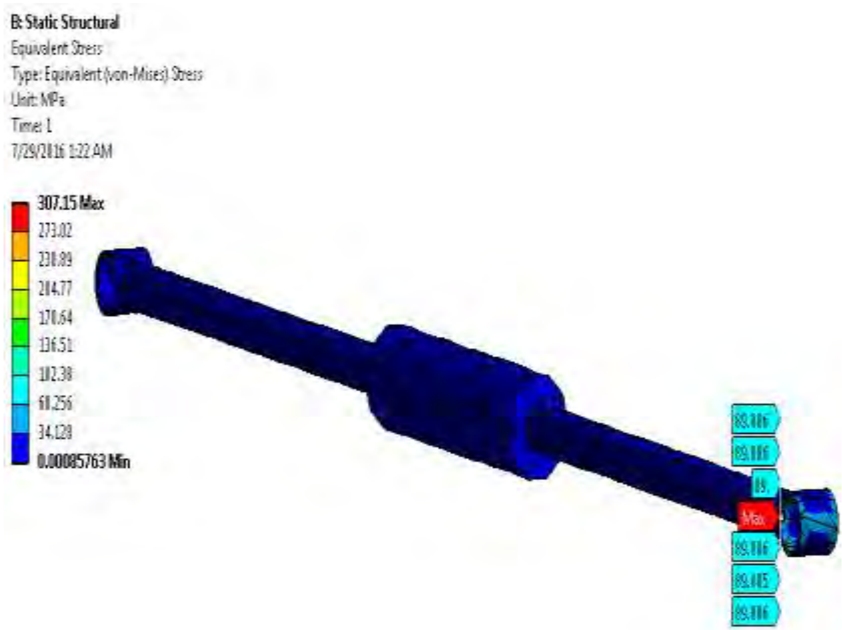


Figure 4. 34 Connecting Rod Stress Alsi 1045 and Material Piston Alumunium A 4032

Figure 4.35 show the result of the simulation semi free dual piston of stress material piston AL GHS 1300 and material connecting rod Alsi 1045. From input data pressure during combustion in 118.609 bar in cylinder one and 1.378 bar in cylinder two. Obtained stress distribution semi free dual piston maximum stress was 211.04 MPa and minimum stress value is 0.00014721 MPa. From analysis greatest stress area were occured in piston pin.

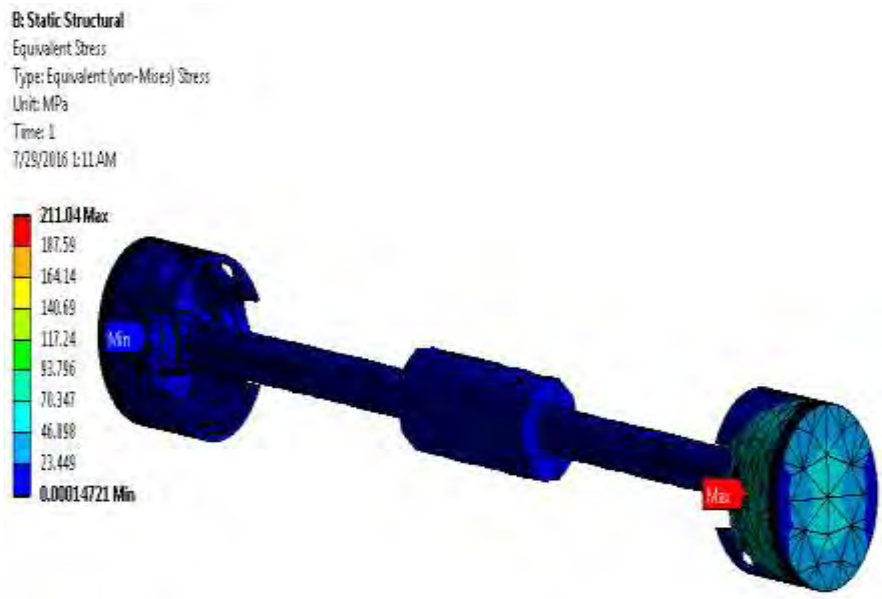


Figure 4. 35 Semi Free Dual Piston Stress Material Piston Alumunium AL GHS 1300 and Material Connecting Rod Alsi 1045

Figure 4.36 show the result of the simulation of stress on connecting rod by using material piston AL GHS 1300 and material connecting rod Alsi 1045. From input data 118.609 bar in cylinder one and 1.378 bar in cylinder two distribution load from piston. Result of the stress distribution connecting rod obtained greatest value was 19.877 MPa. From analysis greatest stress area are occurs in connecting rod connection with piston pin.

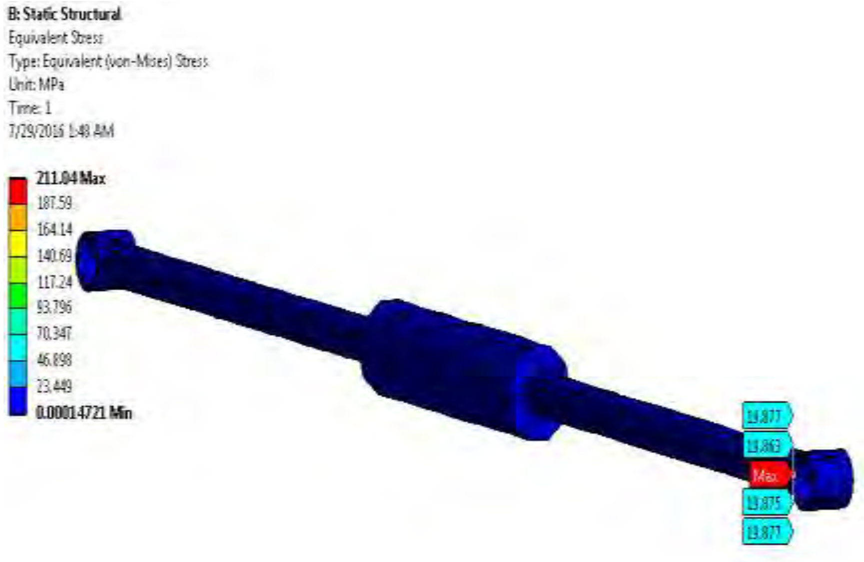


Figure 4. 36 Connecting Rod Stress Alsi 1045 and Material Piston AL GHS 1300

4.6.2 Material C-70

Figure 4.37 show the result of the simulation semi free dual piston of stress material piston Alsi 12 CuNiMg and material connecting rod C-70. From input data pressure during combustion in 118.609 bar in cylinder one and 1.378 bar in cylinder two.Obtained stress distribution semi free dual piston maximum stress was 293.96 MPa and minimum stress value is 0.0008504 MPa. From analysis greatest stress area were occured in piston pin.

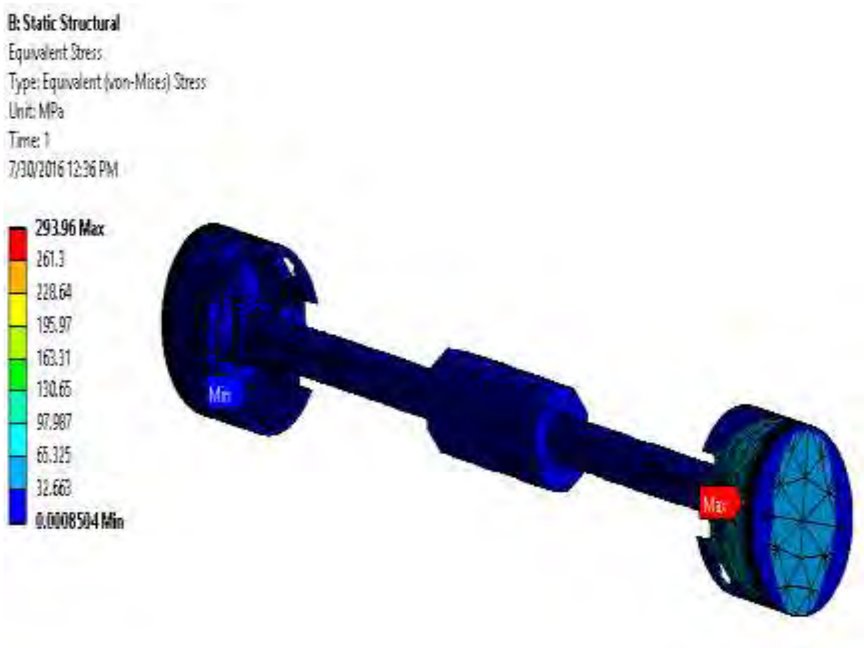


Figure 4. 37 Semi Free Dual Piston Stress Material Piston Alsi 12 CuNiMg and Material Connecting Rod C-70

Figure 4.38 show the result of the simulation of stress on connecting rod by using material piston Alsi 12 CuNiMg and material connecting rod C-70. From input data 118.609 bar in cylinder one and 1.378 bar in cylinder two distribution load from piston. Result of the stress distribution connecting rod obtained greatest value was 85.731 MPa. From analysis greatest stress area are occurs in connecting rod connection with piston pin.

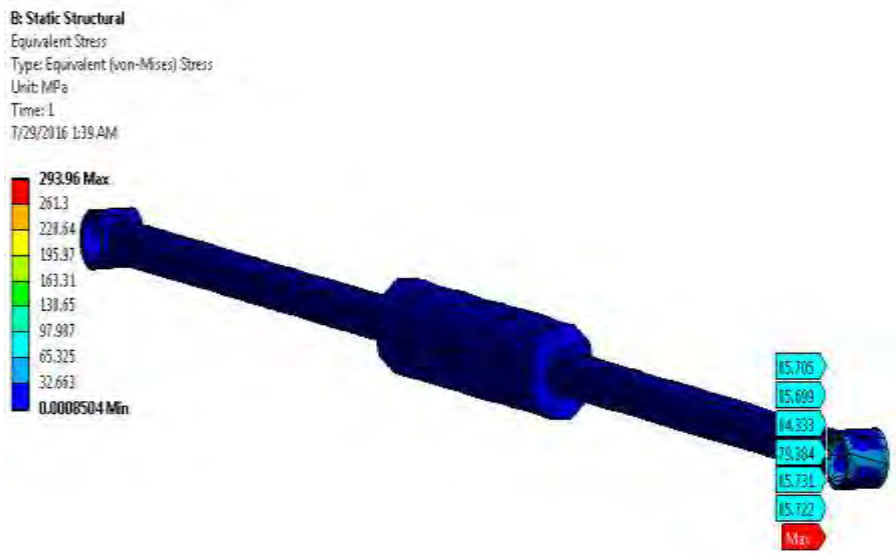


Figure 4. 38 Connecting Rod Stress C-70 and Material Piston Alsi 12 CuNiMg

Figure 4.39 show the result of the simulation semi free dual piston of stress material piston Alumunium A 2618 and material connecting rod C-70. From input data pressure during combustion in 118.609 bar in cylinder one and 1.378 bar in cylinder two. Obtained stress distribution semi free dual piston maximum stress was 286.54 MPa and minimum stress value is 0.00095622 MPa. From analysis greatest stress area were occured in piston pin.

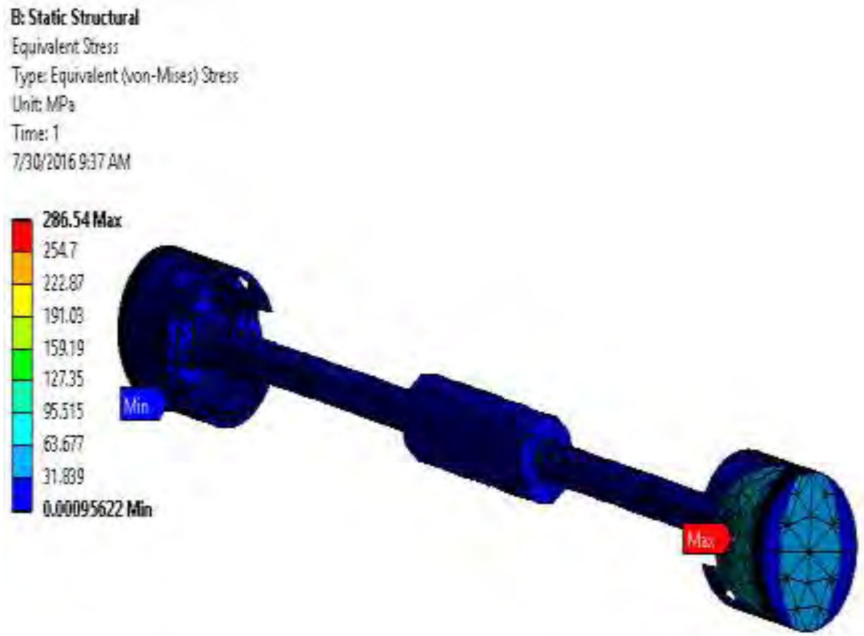


Figure 4. 39 Semi Free Dual Piston Stress Material Piston Alumunium A 2618 and Material Connecting Rod C-70

Figure 4.40 show the result of the simulation of stress on connecting rod by using material piston Alumunium A 2618 and material connecting rod C-70. From input data 118.609 bar in cylinder one and 1.378 bar in cylinder two distribution load from piston. Result of the stress distribution connecting rod obtained greatest value was 69.17 MPa. From analysis greatest stress area are occurs in connecting rod connection with piston pin.

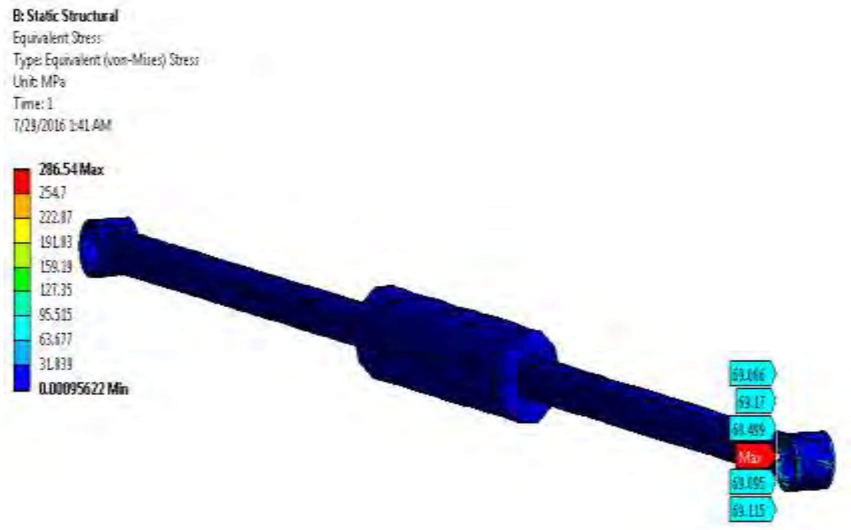


Figure 4. 40 Connecting Rod Stress C-70 and Material Piston Alumunium A 2618

Figure 4.41 show the result of the simulation semi free dual piston of stress material piston Alumunium A 4032 and material connecting rod C-70. From input data pressure during combustion in 118.609 bar in cylinder one and 1.378 bar in cylinder two. Obtained stress distribution semi free dual piston maximum stress was 311.09 MPa and minimum stress value is 0.00085763 MPa. From analysis greatest stress area were occured in piston pin.

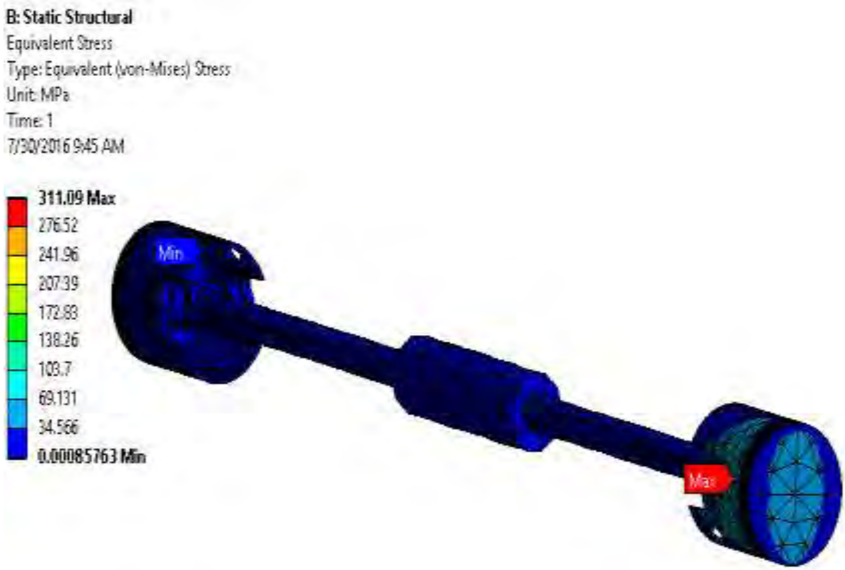


Figure 4. 41 Semi Free Dual Piston Stress Material Piston Alumunium A 4032 and Material Connecting Rod C-70

Figure 4.42 show the result of the simulation of stress on connecting rod by using material piston Alumunium A 4032 and material connecting rod C-70. From input data 118.609 bar in cylinder one and 1.378 bar in cylinder two distribution load from piston. Result of the stress distribution connecting rod obtained greatest value was 92.071 MPa. From analysis greatest stress area are occurs in connecting rod connection with piston pin.

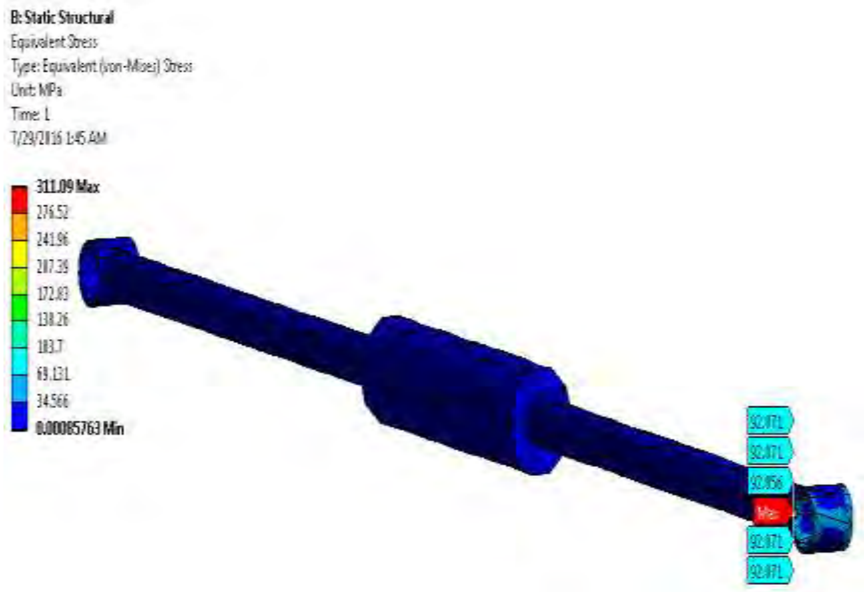


Figure 4. 42 Connecting Rod Stress C-70 and Material Piston Alumunium A 4032

Figure 4.43 show the result of the simulation semi free dual piston of stress material piston AL GHS 1300 and material connecting rod C-70. From input data pressure during combustion in 118.609 bar in cylinder one and 1.378 bar in cylinder two. Obtained stress distribution semi free dual piston maximum stress was 211.02 MPa and minimum stress value is 0.00015015 MPa. From analysis greatest stress area were occured in piston pin.

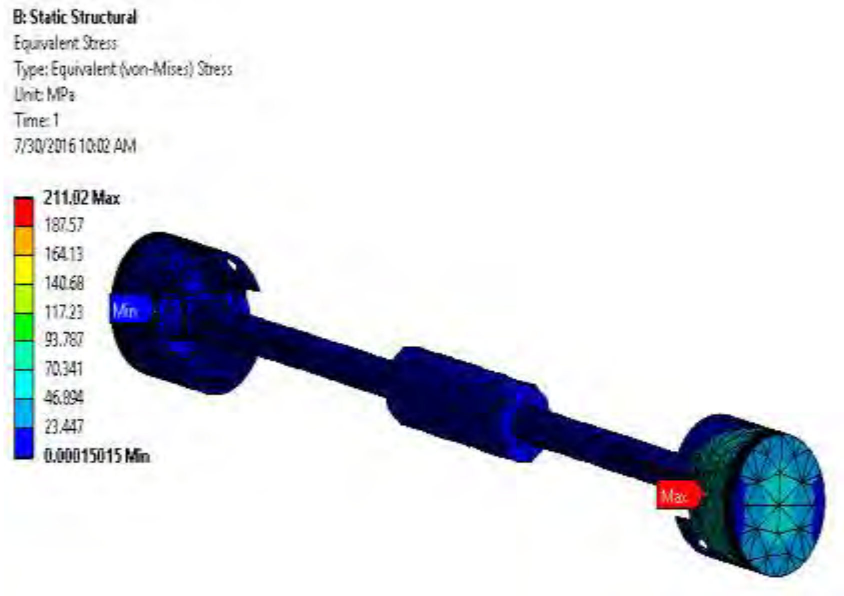


Figure 4. 43 Semi Free Dual Piston Stress Material Piston AL GHS 1300 and Material Connecting Rod C-70

Figure 4.44 show the result of the simulation of stress on connecting rod by using material piston Alumunium A 4032 and material connecting rod C-70. From input data 118.609 bar in cylinder one and 1.378 bar in cylinder two distribution load from piston. Result of the stress distribution connecting rod obtained greatest value was 20.443 MPa. From analysis greatest stress area are occurs in connecting rod connection with piston pin.

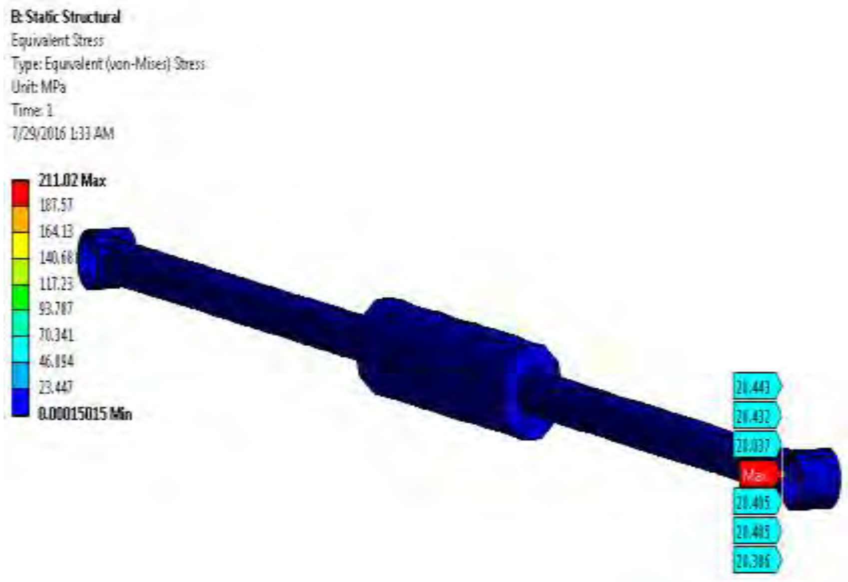


Figure 4. 44 Connecting Rod Stress C-70 and Material Piston AL GHS 1300

4.6 Analysis Data

4.6.1Analysis Mechanical Stress of Piston

From static stress on the simulation finite element method results obtained stress of several piston material, and obtained a table and graph showing the difference stress that occurs due to the combustion pressure on the piston with variations of material. Comparison of the mechanical stress on the piston shows in Table 4.1, charts 4.1,4.2. Mechanical stress also will influence in deformation piston. Comparison of the deformation on the piston shows in Table 4.2 and charts 4.3, 4.4.

Table 4. 1 Comparison Mechanical Stres of Piston

No	Material Piston	Mechanical Stress (MPa)	
		Max	Min
1	Alsi 12 CuNiMg	248.71	0.26979
2	Alumunium A 2618	229.6	0.36602
3	Alumunium A 4032	253.51	0.25433
4	AL GHS 1300	185.52	0.32606

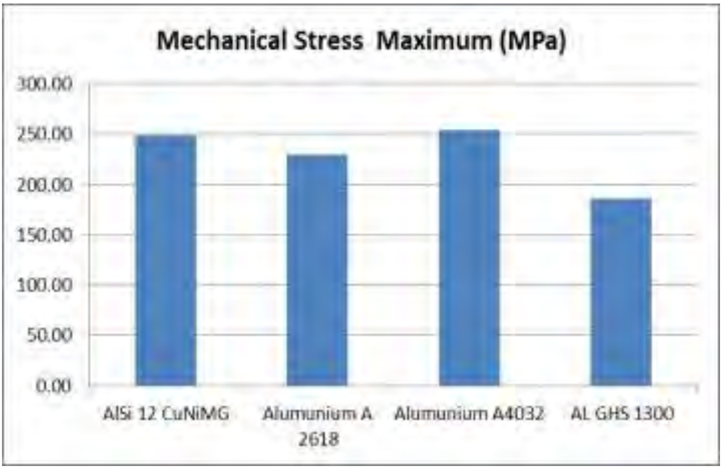


Chart 4. 1 Maximum Mechanical Stress of Piston

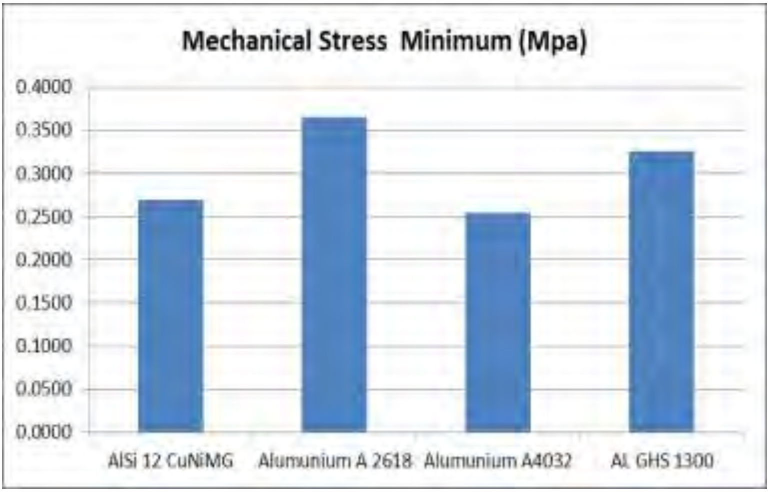


Chart 4. 2 Mechanical Stress Minimum of Piston

From table 4.1 and charts 4.1, 4.2 showing piston material the largest maximum mechanical stress was aluminum A 4032 amounting to 253.51 MPa and piston material that the smallest maximum mechanical stress is AL GHS in 1300 that is 185.52 MPa. While the piston material that the largest minimum mechanical stress is Aluminum A 2618 is equal to 0.36602 MPa and for the smallest minimum stress is AL GHS 1300 amounted to 0.25433 MPa.

Table 4. 2 Comparison Mechanical Stress Deformation of Piston

No	Material Piston	Mechanical Stress (MPa)		Deformation (mm)	
		Max	Min	Max	Min
1	Alsi 12 CuNiMg	248.71	0.26979	0.1606	0.041253
2	Alumunium A 2618	229.6	0.36602	0.15411	0.030519
3	Alumunium A 4032	253.51	0.25433	0.16751	0.045165
4	AL GHS 1300	185.52	0.32606	0.090685	0.0080177

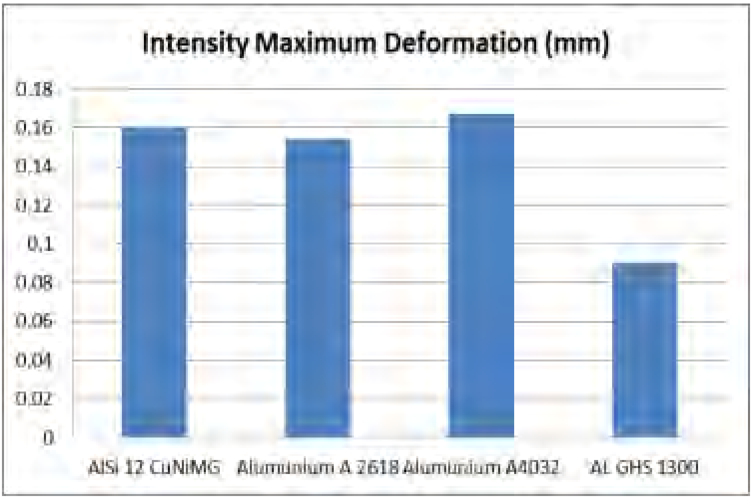


Chart 4. 3 Intensity Deformation Maximum Piston Result Mechanical Stress

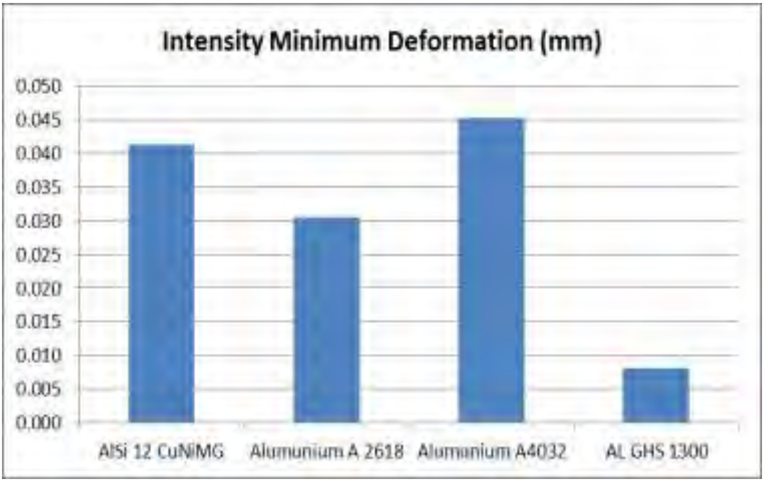


Chart 4. 4 Intensity Deformation Minimum of Piston Result Mechanical Stress

From table 4.2 and chart 4.3, 4.4 showing piston material the largest maximum intensity deformation influence from mechanical stress was aluminum A 4032 amounting to 0.16751 mm and piston material that the smallest maximum deformation is AL GHS 1300 amounting to 0.090685 mm. While the piston material that the largest minimum deformation was Aluminum A 4032 amounting to 0.04517 mm and for the smallest minimum deformation is AL GHS 1300 amounted to 0.00802 mm.

4.6.2 AnalysisThermal Stress Piston

From the analysis of the distribution of thermal piston with material variations on simulation software then obtained temperature that occurs on the piston. From the analysis of steady state thermal analysis is used to input boundary piston model in static stress analysis. Thermal stress that occurs on the piston caused by differences in temperature and thermal expansion properties of each material.Comparison of the thermal stress on the piston were shows in Table 4.3 and charts 4.5, 4.6. Thermal stress also will influence in deformation piston. Comparison of the deformation on the piston can be seen in Table 4.4 and charts 4.7, 4.8.

Table 4. 3 Comparison Analysis Thermal Stress of Piston

No	Material Piston	Thermal Distribution (°C)		Thermal Stress (MPa)	
		Max	Min	Max	Min
1	Alsi 12 CuNiMg	316.85	126.97	70.655	0.1448
2	Alumunium A 2618	316.85	120.5	85.723	0.1578
3	Alumunium A 4032	316.85	124.66	65.57	0.131
4	AL GHS 1300	316.85	102.92	88.81	0.125

Chart 4. 5 Maximum Thermal Stress of Piston

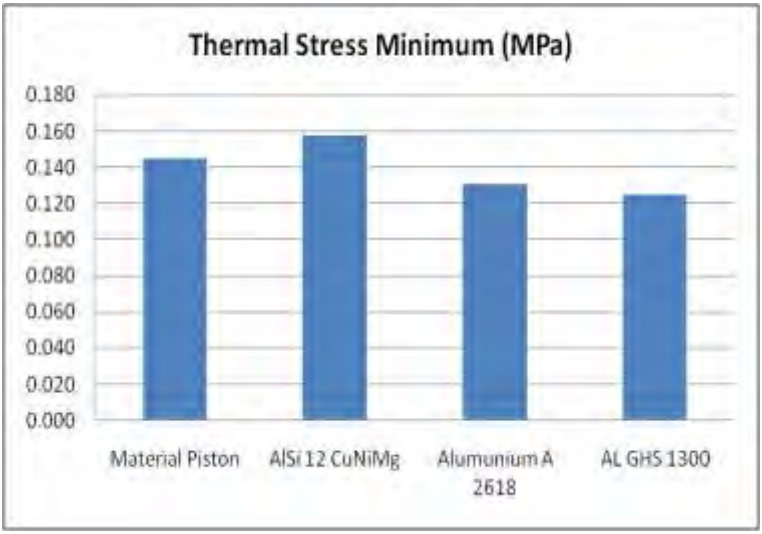


Chart 4. 6 Minimum Thermal Stress of Piston

From table 4.3 and charts 4.5, 4.6 showing piston material the largest maximum thermal stress is AL GHS 1300 amounting to 88.881 MPa and piston material that the smallest maximum thermal stress is Alumunium A 4032 that is 65.57 MPa. While the piston material that the largest minimum thermal stress is Aluminum A 2618 is equal to 0.158 MPa and for the smallest minimum stress is AL GHS 1300 amounted to 0.125 MPa.

Table 4. 4 Comparison Analysis Thermal Stress Deformation of Piston Using Material Selection

No	Material Piston	Thermal Stress (MPa)		Deformation (mm)	
		Max	Min	Max	Min
1	Alsi 12 CuNiMg	70.655	0.1448	0.08262	0.000313
2	Alumunium A 2618	85.723	0.1578	0.10387	0.000931
3	Alumunium A 4032	65.57	0.131	0.076967	0.000309
4	AL GHS 1300	88.81	0.125	0.074	0.00185

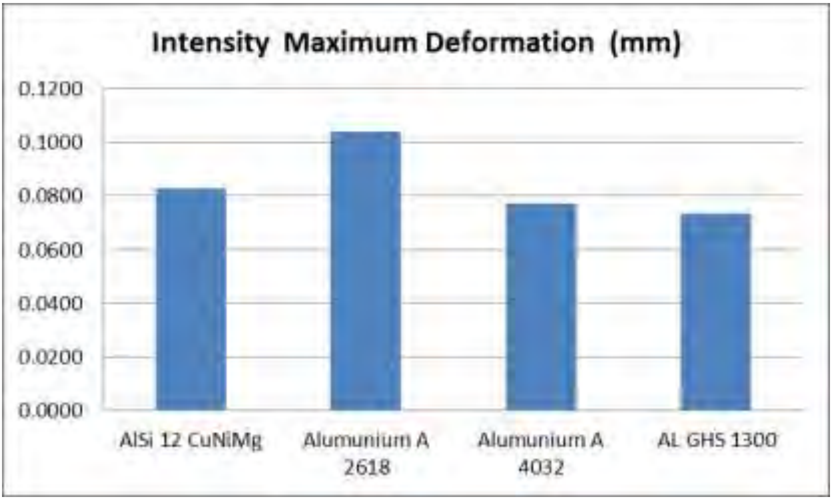


Chart 4. 7 Intensity Maximum Deformation of Piston Result Thermal Stress

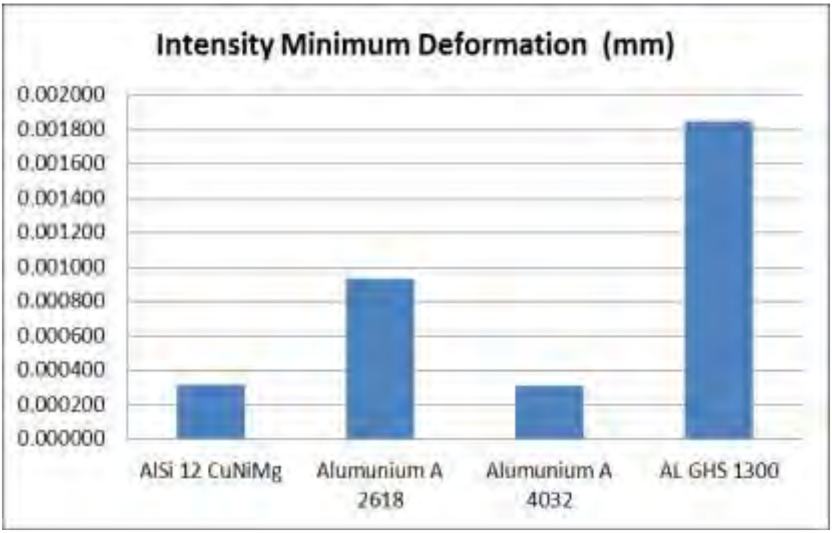


Chart 4. 8 Intensity Minimum Deformation of Piston Result Thermal Stress

From table 4.4 and charts 4.7, 4.8 showing piston material the largest maximum deformation influence from mechanical stress is aluminum A 4032 amounting to 0.1039 mm and piston material that the smallest maximum deformation is AL GHS 1300 amounting to 0.0735 mm. While the piston material that the largest minimumdeformation is AL GHS 1300 amounting to 0.001851 mm and for the smallest minimum deformation is AL GHS 1300 amounted to 0.000309 mm.

4.6.3 Analysis Thermo Mechanical Stress Piston

From the analysis of thermo mechanical stress piston thermal stress analysis coupled with mechanical stress on simulation program. From various material selection obtained thermo mechanical stress. The thermo mechanical stress influenced deformation of piston.Comparison of the thermo mechanicalstress on the piston shows in table 4.5 and charts 4.9, 4.10. Thermo mechanical stress also will influence in deformation piston. Safety factor from thermo mechanical stress analysis piston shows in charts 4.11 Comparison of the deformation on the piston shows in table 4.6 and charts 4.12, 4.13.

Table 4. 5 Comparison Analysis Thermo Mechanical Stress Piston Used Selected Material

No	Material Piston	Thermo Mechanical Stress (MPa)		Safety Factor
		Max	Min	
1	Alsi 12 CuNiMg	253.37	0.23807	1.34
2	Alumunium A 2618	236.96	0.29159	1.77
3	Alumunium A 4032	259.27	0.27209	1.21
4	AL GHS 1300	199.42	0.26023	6.12

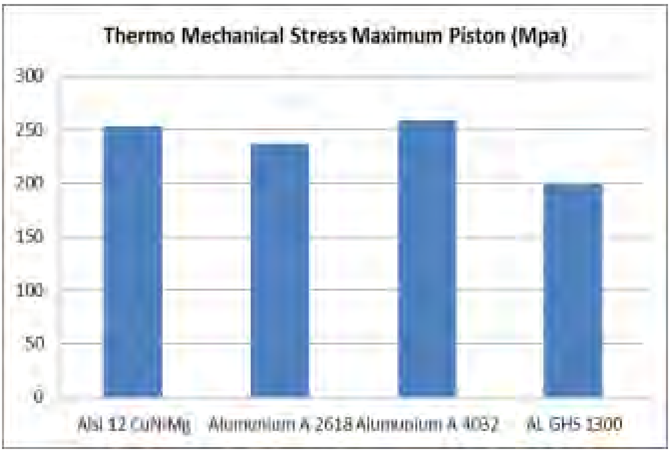


Chart 4. 9 Maximum Thermo Mechanical Stress of Piston

Chart 4. 10 Minimum Thermal Stress of Piston

From table 4.5 and charts 4.9, 4.10 showing piston material the largest maximum thermo mechanical stress was Alumunium A 4032 amounting to 259.27 MPa and piston material that the smallest maximum thermal stress is AL GHS 1300 value was 199.42 MPa. While the piston material that the largest minimumthermo mechanical stress was Aluminum A 2618 is equal to 0.2915 MPa and for the smallest minimum thermo mechanical stress was Alsi 12 CuNiMg amounted to 0.23807 MPa.

Chart 4. 11 Safety Factor Piston

From chart 4.11 result analysis thermo mechanical stress input load maximum pressure during combustion 118.609 bar and temperature piston crown 590 K. Safety factor material piston selection AL GHS 1300 have the largest value 6.12 and the lowest Alumunium A 4032 value 1.77.

Table 4. 6 Comparison Analysis Thermo Mechanical Stress Deformation of Piston Using Material Selection

No	Material Piston	Thermo Mechanical Stress (MPa)		Deformation (mm)	
		Max	Min	Max	Min
1	Alsi 12 CuNiMg	253.37	0.23807	0.14736	0.04053
2	Alumunium A 2618	236.96	0.29159	0.14919	0.03056
3	Alumunium A 4032	259.27	0.27209	0.15339	0.04436
4	AL GHS 1300	199.42	0.26023	0.1000	0.00869

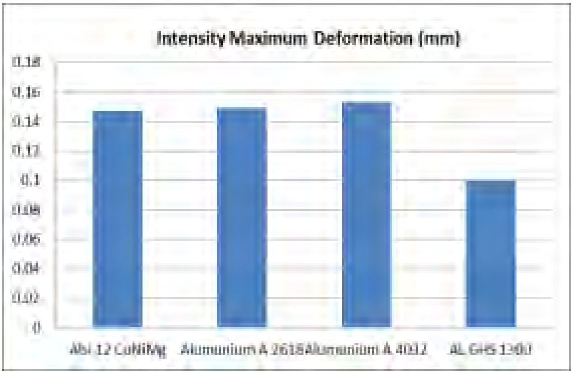


Chart 4. 12 Intensity Maximum Deformation of Piston Result Thermo Mechanical Stress

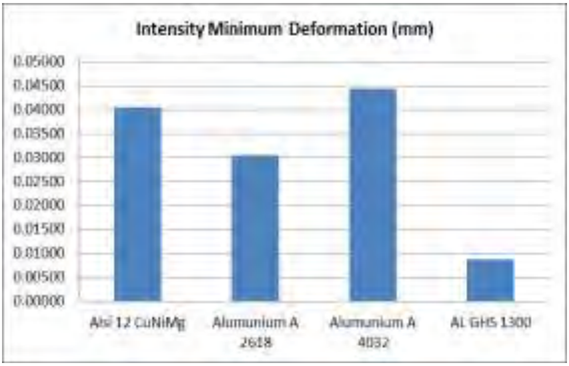


Chart 4. 13 Intensity Minimum Deformation of Piston Result Thermo Mechanical Stress

From table 4.6 and charts 4.12, 4.13 showing piston material the largest maximum deformation influence from thermo mechanical stress was aluminum A 4032 amounting to 0.15339 mm and piston material that the smallest maximum deformation was AL GHS 1300 amounting to 0.1 mm. While the piston material that the largest minimumdeformation is Aluminum A 4032 amounting to 0.04436 mm and for the smallest minimum deformation is AL GHS 1300 amounted to 0.00869 mm.

4.6.4 Comparison Stress of Piston

From the result mechanical stress, thermal stress, and thermo mechanical stress. Obtained result that mechanical stress from input load maximum pressure during combustion have high influenced than thermal stress from temperature distribution to thermo mechanical stress occurred in piston. Table 4.7 and chart 4.14 shows result comparison stress piston with selected material. Maximum mechanical stress was occurred in material piston Alumunium A 4032 value 253.51 MPa. Maximum thermal stress was occurred in material piston AL GHS 1300 value 88.81 MPa. For thermo mechanical stress maximum mechanical stress was occurred in material piston Alumunium A 4032. Based on thermo mechanical stress of piston and safety factor material AL GHS 1300 have a greatest consideration used for selected material piston.

Table 4. 7 Comparison Stress of Piston

No	Material	Mechanical Stress (MPa)	Thermal Stress (MPa)	Thermo Mechanical Stress (MPa)
1	Alsi 12 CuNiMg	248.71	70.655	253.37
2	Alumunium A 2618	229.6	85.723	236.96
3	Alumunium A 4032	253.51	65.57	259.27
4	AL GHS 1300	185.52	88.81	199.42

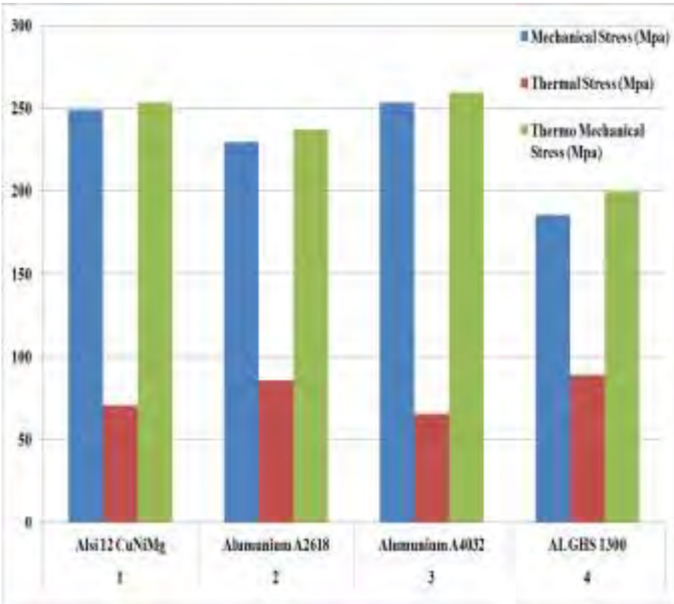


Chart 4. 14 Comparison Stress of Piston

4.6.5 Comparison Distribution Stress of Connecting Rod

From static stress simulation finite element analysis results obtained stress of connecting rod material using combination selections piston material, piston pin material, bearing material, piston ring material for distribution stress. Obtained a table and charts showing the difference stress that occurs with variations of material selected. Comparison of the connecting rod stress shows in table 4.8 and charts 4.15. From connecting rod stress analysis safety factor material show in chart 4.16.

Table 4. 8 Comparison Distribution Mechanical Stress of Connecting Rod

No	Material Piston and Connecting Rod	Mechanical Stress (MPa)	Safety Factor
1	Alsi 12 CuNiMg + Alsi 1045	83.24	3.7242
2	Alumunium A 2618 + Alsi 1045	67.135	4.6176
3	Alumunium A 4032 + Alsi 1045	89.086	3.4798
4	AL GHS 1300 + Alsi 1045	19.877	15.5959
5	Alsi 12 CuNiMg + C-70	85.731	6.6954
6	Alumunium A 2618 + C-70	69.17	8.2984
7	Alumunium A 4032 + C-70	92.071	6.2343
8	AL GHS 1300 + C-70	20.443	28.0781

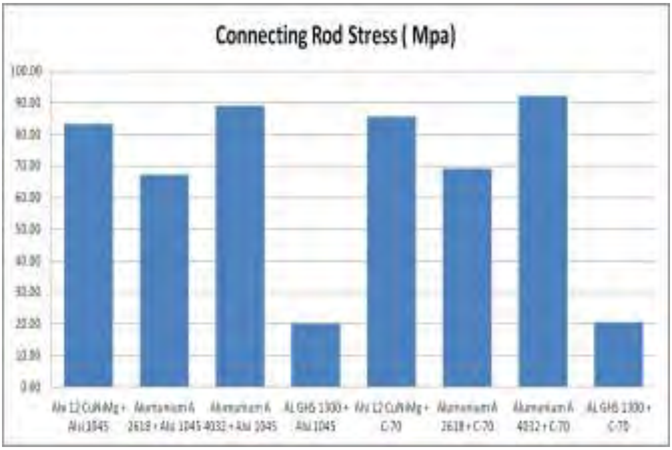


Chart 4. 15 Comparison Connecting Rod Stress

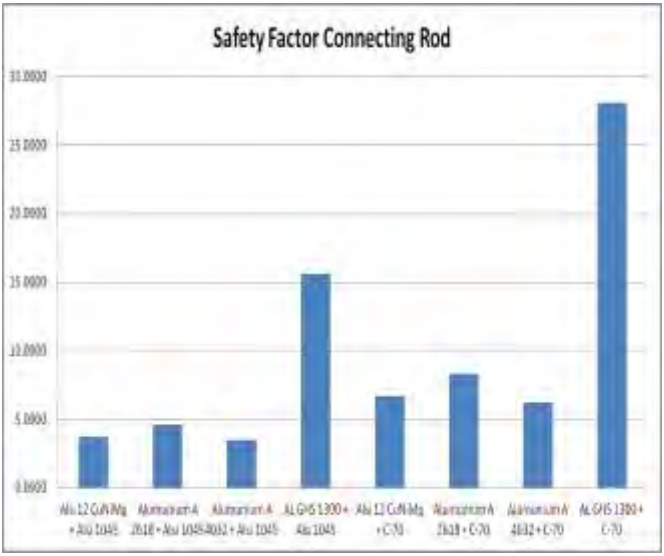


Chart 4. 16 Comparison Safety Factor Connecting Rod

From table 4.8 and charts 4. 15 shows combination piston and connecting rod material for analysis the connecting rod stress. The largest connecting rod stress are using combination piston material Alumunium A 4032 and material connecting rod C-70 that is 92.071 MPa. The smallest connecting rod stress are using combination piston material AL GHS 1300 and material connecting rod Alsi 1045 value 19.877 MPa. Based on analyzed stress distribution all material used have good feasibility for used in application design semi free piston two stroke diesel engine dual opposite. The largest stress that occurs in connecting rod connection with piston pin bearing area. Safety factor material the largest was used combination piston material AL GHS 1300 and C-70 amount to 28.0781. The lowest safety factor material was using combination piston material Alumunium A 4032 amount to 3.4798. Based on mechanical stress and safety factor connecting rod C-70 with combination piston material AL GHS 1300 have a greatest consideration for selected material connecting rod.

APPENDIX

ATTACHMENT 1

General data modeling from design semi free piston two stroke diesel engine dual opposite

Bore [mm]	52.9
Stroke [mm]	64.5
Connecting Rod Length [mm]	286.0
Piston Pin Offset [mm]	0.00
Displacement/Cylinder [liter]	0.142
Total Displacement [liter]	0.284
Number of Cylinders	2
Compression Ratio	21.00
Bore/Stroke	0.820
IVC [CA]	-120
EVO [CA]	127
IVO [CA]	120
EVC [CA]	-127

ATTACHMENT 2

Result Simulation Prediction Performance Semi Free Piston Diesel Engine Dual Opposite

Brake Power [kW]	9.3
Brake Power [HP]	12.5
Brake Torque [N-m]	21.1
IMEP [bar]	10.54
FMEP [bar]	5.52
PMEP [bar]	0.00
Air Flow Rate [kg/hr]	137.6
BSAC [g/kW-h]	14805
Fuel Flow Rate [kg/hr]	4.0
BSFC [g/kW-h]	433.8
Volumetric Efficiency [%]	118.7

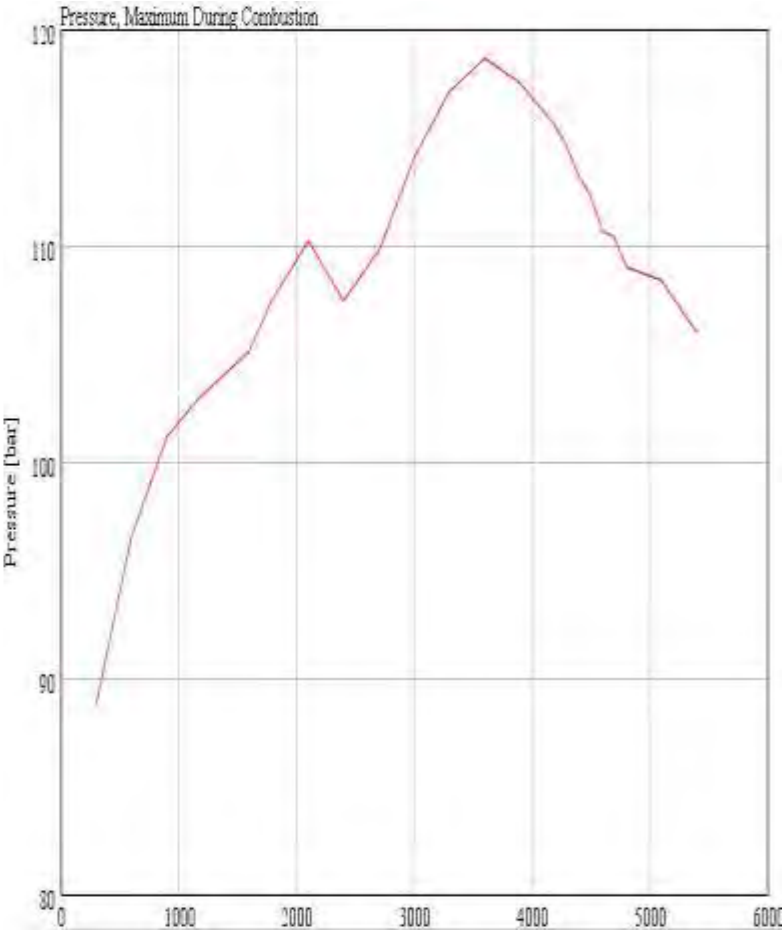
ATTACHMENT 3

Table Result Gas Structure Heat Transfer

	Area [mm^2]	hg_eff [W/m^2-K]	Tg_eff [K]	T_wall [K]	Q_conv [W]	Q_rad [W]	Q_total [W]	Q_flux [kW/m^2]
Piston 1	1271	965	1207	590	586	171	757	730
Piston 2	980	965	1207	590	452	132	583	730
Piston 3	397	965	1207	590	183	53	236	730
Head 1	1213	965	1207	550	606	163	769	769
Head 2	772	965	1207	550	386	104	490	769
Head 3	221	965	1207	550	110	30	140	769
Cylinder 1	1749	625	1139	450	657	96	753	485
Cylinder 2	3496	221	787	450	245	1	246	71
Cylinder 3	5245	104	580	450	60	0	60	11

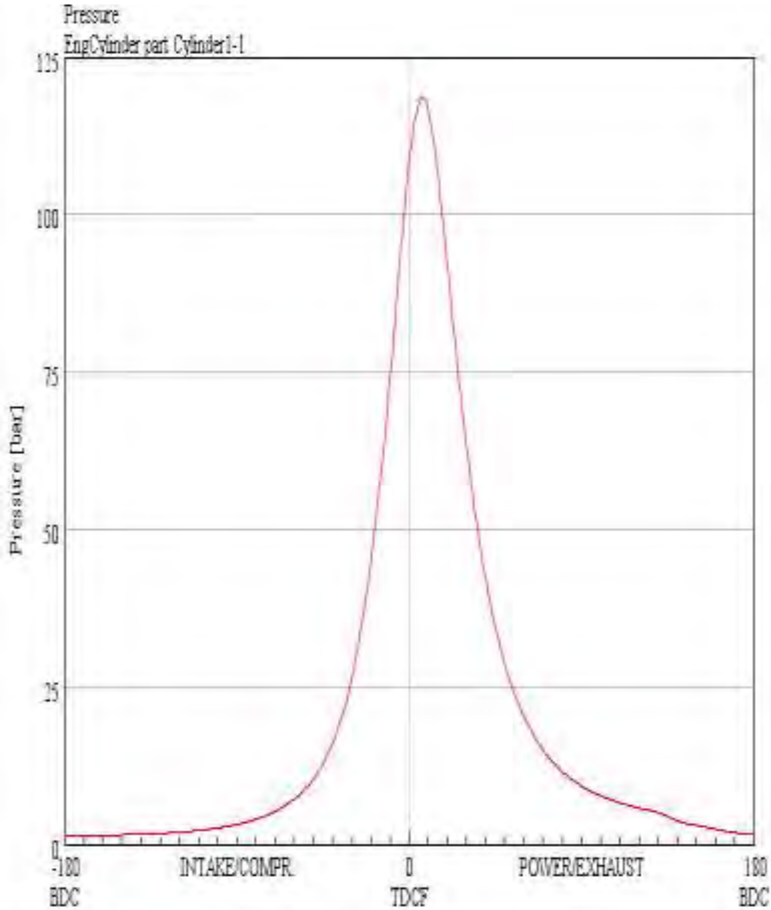
ATTACHMENT 4

Graph Pressure maximum during combustion based on rpm engine.

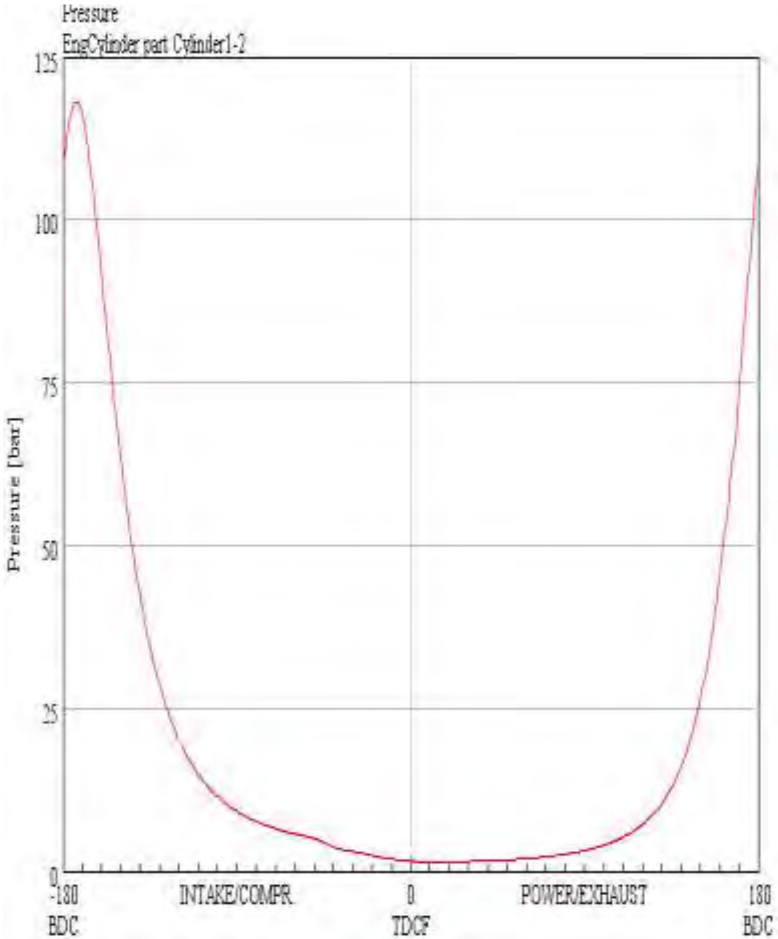


ATTACHMENT 5

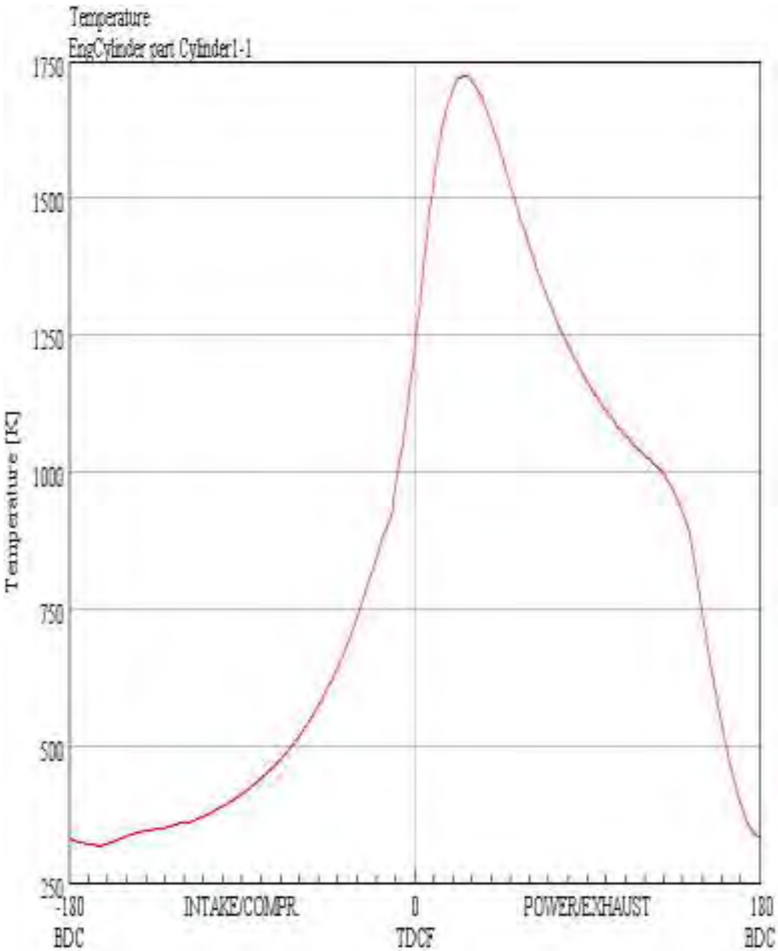
Graph Pressure Maximum Cylinder 1 During Combustion based on crank angle at RPM 3600.



ATTACHMENT 6
Graph Pressure Minimum Cylinder 2 During Combustion based on crank angle at RPM 3600.

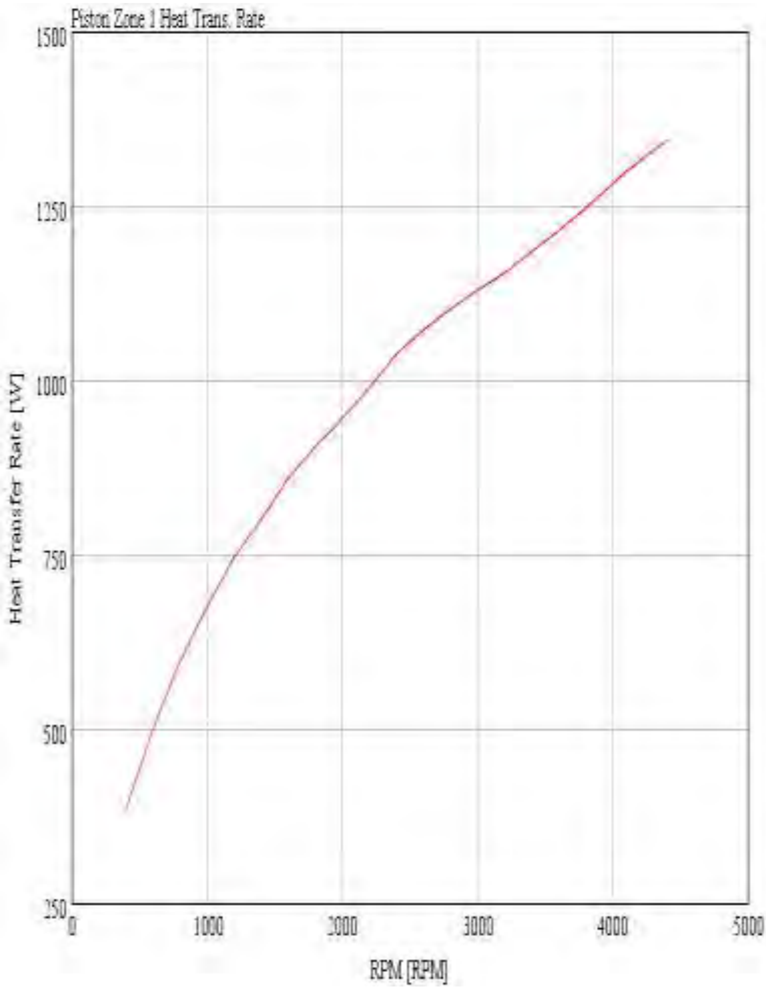


ATTACHMENT 7
Graph Temperature During Combustion Engine based on crank angle.



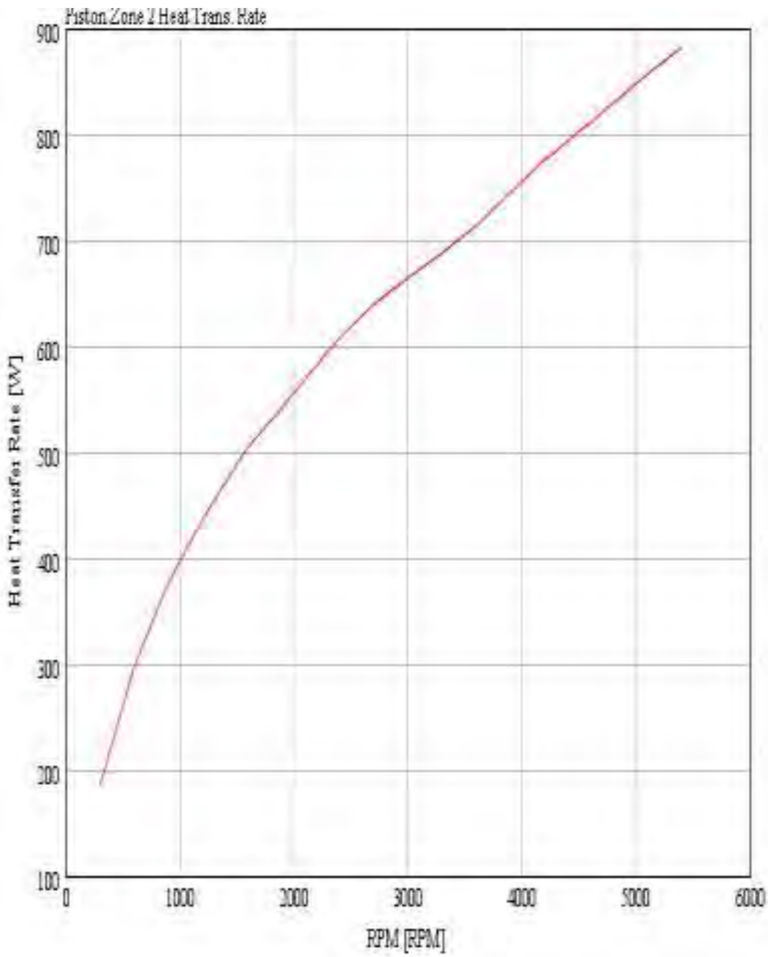
ATTACHMENT 8

Graph Piston Ring area Gas Heat Transfer Rate During Combustion Engine based on RPM engine.



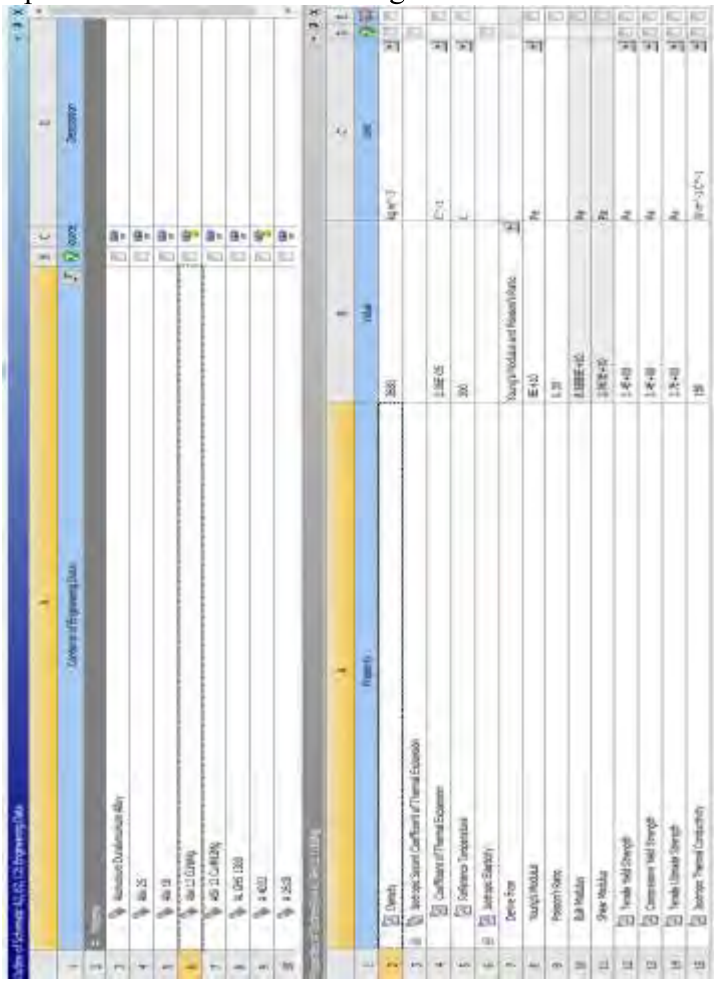
ATTACHMENT 9

Graph Piston skirt area Gas Heat Transfer Rate During Combustion Engine based on RPM engine.



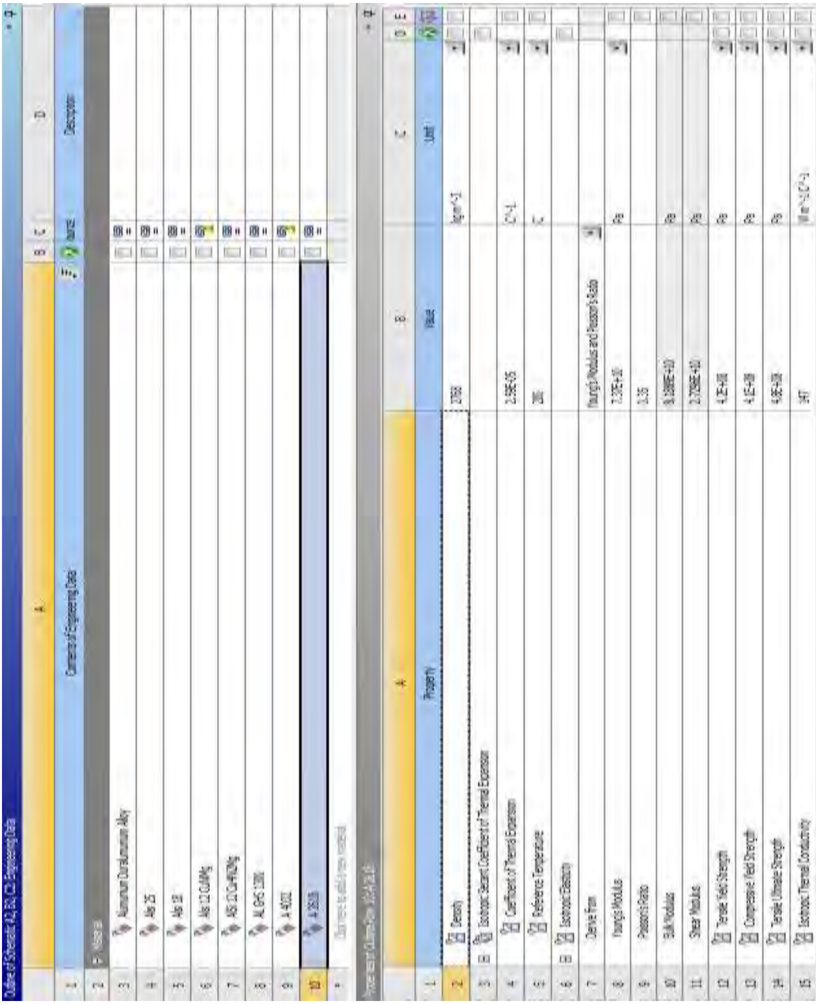
ATTACHMENT 10

Input Material Alsi 12 CuNiMg



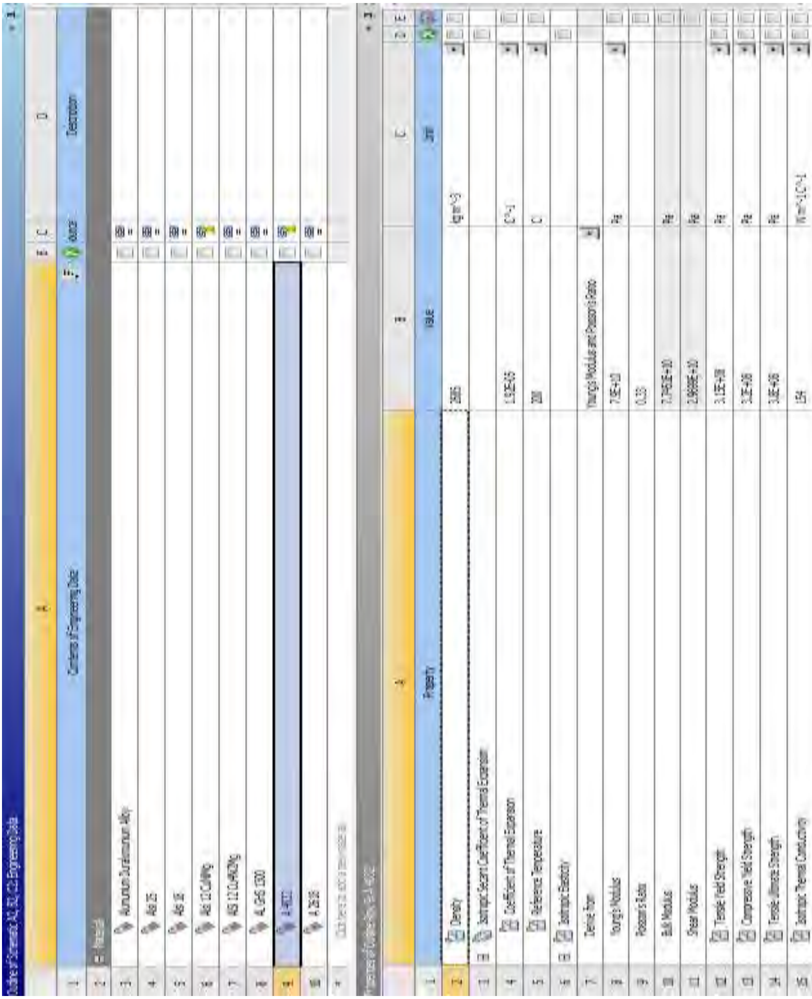
ATTACHMENT 11

Input Material Alumunium A 2618



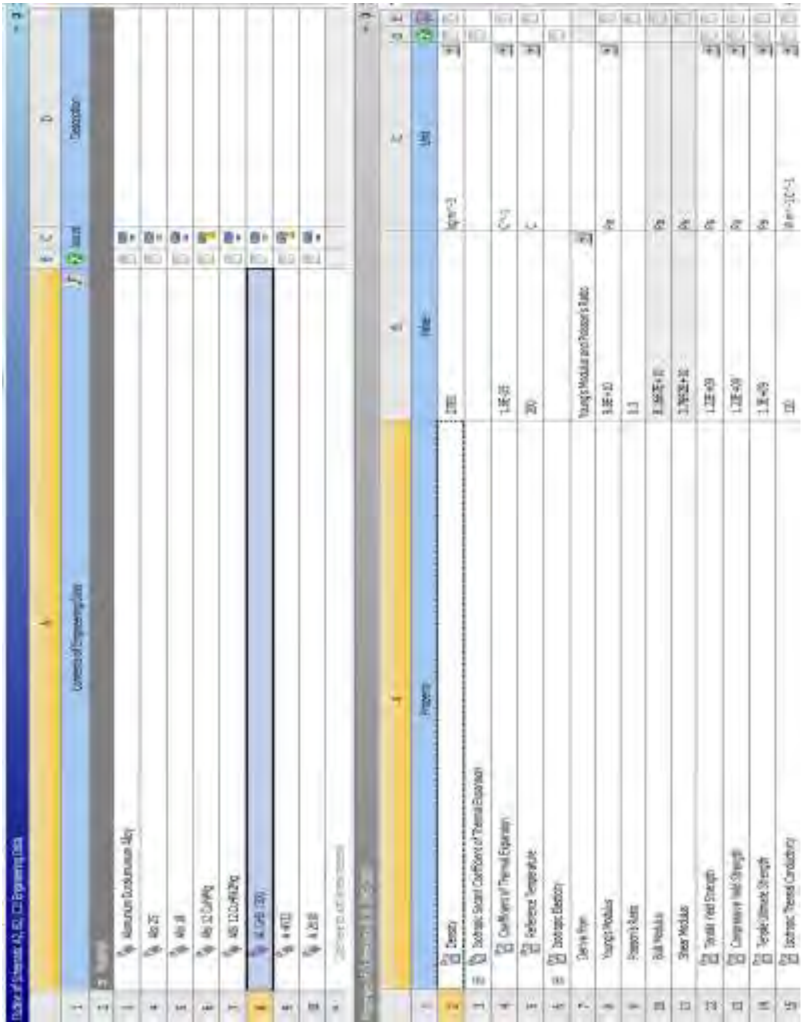
ATTACHMENT 12

Input Material Alumunium A 4032



ATTACHMENT 13

Input Material AL GHS 1300



CHAPTER V
CONCLUSION AND SUGGESTION

5.1 Conclusion

From the results of research analysis it was concluded that:

1. From the analysis of mechanical stress piston using variation material obtained the largest maximum stress occurs in the material aluminum A 4032 the value was 253.51 MPa. While the smallest mechanical stresses occured in material AL GHS 1300 the value was 185.52 MPa.

2. From the analysis of thermal stress of the piston using variation material obtained greatest stress occurs in the material AL GHS in 1300 the value was 88.881 MPa. While the smallest thermal stress occurs in the material aluminum A 4032 the value was 65.57 MPa.

3. From the results analysis of thermo mechanical stress piston using some material obtained largest maximum stress occurs in the material aluminum A 4032 the value was 259.27 MPa. While the smallest maximum Thermo mechanical stress occurred in material AL GHS in 1300 the value was 199.42 MPa. From the analysis thermo mechanical stress obtained that the mechanical stress of piston have high influenced for thermo mechanical stress than thermal stress of piston. Based on thermo mechanical stress of piston

and safety factor, material piston AL GHS 1300 have a greatest consideration used for selected material piston.

4. For connecting rod stress analysis using combination of piston and connecting rod. The largest maximum stress was occur using material connecting rod C-70 and material piston Alumunium A 4032, for distributed stress the value was 92.071 MPa. For the lowest maximum stress was occur using material connecting rod Alsi 1045 and material piston AL GHS 1300 the value was 19.877 MPa. Based on mechanical stress and safety factor connecting rod, material connecting rod C-70 with combination piston material AL GHS 1300 have a greatest consideration for selected material connecting rod.

5.2 Suggestion

In this research selection material only consider to strength material was chosen, so in the future necessary for analyzed stress using material selection based on economy aspect.

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